Cost-Effective 3R Roadside Safety Policy for Two-Lane Rural Highways

FINAL REPORT

to

Illinois Department of Transportation

by

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16. Abstract

The purpose of this research was to investigate the effect of clear zone widths on accidents and to determine the "break-even" traffic volumes and clear zone widths where accident savings equalled roadside improvement costs. Although sufficient data was not available to determine the statistically significant combined effects of clear zone widths and traffic volumes on accident frequency, some very logical trends were observed which provided the basis for accident prediction models and cost-safety-effective analyses.

The cost of clearing the roadside of fixed objects (trees, culvert headwalls and entrances) was generally greater than the present worth of the cost of all collisions involving these objects for most highway segments. For those segments whose accident costs were higher, remedial action should be considered. Generally, these segments have higher ADTs than other segments. In contrast, for all segments examined the cost of flattening the side slopes and removing all fixed objects exceeded the present worth of the savings from the predicted reduction in run-off-road accidents.

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Executive Summary

A roadside policy may be described in terms of two variables: (a) the width of the clear zone, the area clear of fixed objects, and (b) the lateral slope of the embankment and drainage ditches. The specific objective of this project was to investigate whether a cost-effective clear zone width could be determined as a function of average daily traffic for two lane, rural roads in Illinois. Two recent policy options were an 18 foot clear zone and a 30 foot clear zone. Therefore, these two widths were the focus of a portion of the research.

The overall research design sought to compare the savings in accidents avoided by a wider clear zone with the cost of removing obstacles from the roadside. Much of the effort was focused on understanding the effect of roadside characteristics on accidents, at both the micro and macro level. This summary briefly describes the results of these investigations and the conclusions drawn from them.

Single-vehicle, run-off-road accidents, are generally regarded as an appropriate indicator of the hazards associated with the roadside area. Such accidents may result when vehicles leave the roadway for a variety of reasons. The number of such accidents on two-lane, rural roads in Illinois in recent years is about 6,000 per year, or about 25% of all accidents on such roads. The frequency of vehicles leaving the roadway for any reason was estimated as about once in every 500 miles; however, only about one in 100 such events enter the roadside area beyond the shoulder.

Microscopic Studies

To investigate the circumstances of run-off-road accidents in detail, a sample of 1328 detailed accident investigations was obtained from the

Multidisciplinary Accident Investigation Program. The accidents were selected to include accidents from a variety of conditions: roadway surface; horizontal and vertical alignment; and light condition. The sample is not representative of all crashes.

In 89% of the cases examined, the vehicle left the roadway and struck an object; by comparison, only 55% of single-vehicle, run-off-road accidents on Illinois two-lane, rural roads involved a fixed object. Of the vehicles striking an object, about 55% came to rest within a lateral distance of 18 feet of the pavement; 75% came to rest within 30 feet of the pavement. For vehicles not striking an object, these proportions were 45% and 60% respectively. The speed of the vehicle is the most important factor in explaining the lateral distance traveled. Other important factors are horizontal and vertical alignment, ambient lighting, surface condition (wet/dry) and angle of departure. Excursions into the roadside area are a significant nighttime problem on both tangent and curved alignments.

Macroscopic Studies

A concurrent analysis examined the frequency of single-vehicle, run-off-road accidents on Illinois two-lane, rural roads in relation to roadway and roadside characteristics. In the final analyses, a sample of 53 segments of road was used; the accident records were for 1980-1985. Because of the limited amount of data that it was possible to collect within the time constraints of the project, as well as other factors, the results were not statistically significant for the variables describing roadside characteristics. Some clear trends did emerge from the analysis however.

The total number of accidents per mile is strongly correlated and increasing with average daily traffic (ADT), explaining over 50% of the

variation in the sample. As compared with a low ADT road with less than 1000 vehicles per day, a road with 1,000-2,000 vehicles per day has three times as many accidents per mile; a road with 2,000-3,000 vehicles per day has five times as many accidents per mile; a road with 3,000-4,000 vehicles per day has eight times as many accidents per mile; and a road with over 4,000 vehicles per day has over 13 times as many accidents per mile. Therefore, it is clear that priority should be given to higher ADT roads in improving the roadside; however, no specific ADT threshold is revealed by this analysis.

Clear zone width and lateral slope together explain an additional 10% of the variation; however, this additional explanation is <u>not</u> statistically significant for this sample size. A comparison of the estimated coefficients suggests that roadsides with 18 foot clear zones in the sample had about 20% more accidents per mile than roadsides with 30 foot clear zones.

In comparison, larger effects were estimated for roadside slope. For example, roadsides with slopes equal to or steeper than 3:1 had about twice as many accidents per mile than roadsides with slopes equal to or flatter than 5:1. Likewise, roadsides with 3:1 slopes had about 50% more accidents per mile than roadsides with slopes equal to or flatter than 4:1. These results should be viewed as hypothetical since they are not statistically significant for the sample size available. Efforts to estimate significant relationships for variables measuring the location of fixed objects in the roadside, such as trees, utility poles and fences, were unsuccessful.

<u>Cost-Effectiveness Analyses</u>

The final element of the research sought to examine the trade-off of accident savings and roadside improvement cost. This effort was frustrated

not only by the lack of statistically significant results for accidents, but also by the lack of detailed data on the number and size of roadside objects and the cost of removing them.

Two analyses were performed in an attempt to examine the cost-effectiveness of roadside improvement alternatives. The first analysis focused on the cost of collisions with fixed objects in the roadside versus the cost of removing these objects. This approach is recommended as a screening device for identifying highway segments with high accident costs relative to roadside improvement costs. Given the mean cost of removing an object, those segments whose present worth of accident costs exceeds the cost of object removal to a width of 18 or 30 feet are readily identified. This technique reveals that higher ADT roads are somewhat more likely to have excessive accident costs. This analysis also suggests that a statewide program to remove objects with a relatively low removal cost, such as trees, may be highly cost-effective in reducing accident costs.

A review of average roadside improvement unit costs for recent two-lane, rural highway projects in Illinois revealed substantially higher costs than reported by Graham and Harwood (1982). The Illinois costs agree more closely with those reported by Glennon and Wilton (1974) who suggested that "relatively little effectiveness can be gained by implementing roadside safety improvements on highways other than freeways."

The second analysis compared the present worth of the estimated reduction in accident costs to the cost of flattening slopes and removing all objects from the roadside. According to this analysis, neither of the policy alternatives considered is cost-effective: 4:1 slopes and 18 foot clear zones, or 6:1 slopes and 30 foot clear zones. For this reason also,

programs targeted to removing specific, readily identified hazards, such as trees, utility poles and culvert headwalls throughout the state are more likely to be cost-effective than improving the roadside of a relatively few roads to a high standard.

Conclusions

The following conclusions may be drawn from the analysis and the general research experience:

1. Little evidence was found to indicate that a specific clear zone width would be cost-effective for a roadway in a certain ADT class. It is noted that accident frequency generally declines with increasing clear zone width and increases with increasing ADT. Sufficient data were not available to examine the combined effect of clear zone width and ADT on accident frequency.

2. The accident analyses suggest that roads with steep lateral slopes ($\geq$ 3:1) and narrow clear zones ($\leq$ 15 feet) had over twice as many accidents per mile as roads with flat lateral slopes ($\leq$ 5:1) and wide clear zones ($\geq$ 28 feet). This result was also observed in the analysis of NCHRP data compiled in an earlier project. These relatively hazardous road segments should receive high priority for reconstruction.

3. The cost of clearing the roadside of fixed objects (trees, culvert headwalls and entrances) is generally greater than the present worth of the cost of collisions involving these objects for most highway segments. For those segments whose accident costs are higher, remedial action should be considered. Generally, these segments have higher ADTs than other segments. In contrast, for all segments examined the cost of flattening the side slopes and removing all fixed objects exceeded the present worth of the savings from the predicted reduction in run-off-road accidents.

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Preface

This study was undertaken at the request of the Bureau of Location and Environment, Division of Highways, Illinois Department of Transportation. We wish to express out appreciation to M. J. Macchio and A. J. Gazda for the opportunity to investigate this important problem. John Sanford of the Division of Highways served as project monitor for this research. We have found him to be knowledgeable and helpful, as well as interested and supportive of the approaches to cost-effectiveness analysis we have sought to introduce in this research. DeWayne Meyer of the Division of Traffic Safety and Eugene Day of the Office of Planning and Programming were helpful in arranging for accident and descriptive data for two-lane highways.

Several students have assisted our data collection and analysis efforts. We thank Susan Boyce, Anne Brinkman, Teresa Brown, Diane Kohl-becker, Christina Phillipps, Preston Staley and Laura Tubbs for their good work.

Without the patience and good humor of our secretaries, the results of this research would never be seen by others. In this regard, we thank Bev Casey and Carol Snyder.

David Boyce and Rudolph Mortimer

Chapter 1

Objectives and Design of the Study

The overall purpose of this study is to provide an objective basis for the evaluation of the cost-effectiveness of alternative roadside policy guidelines for the Illinois two-lane rural highway system. These policy guidelines are intended for application in IDOT's 3R (resurfacing, restoring and rehabilitating) program. More specifically, the objective of analysis is to determine: (a) whether roadside characteristics have a statistically significant relationship with the occurrence and severity of accidents; and (b) whether the cost of a higher quality roadside is offset by the potential savings in accidents that may result from its adoption.

A roadside design policy is mainly characterized in terms of two factors: (a) the width of the clear zone, the roadside area including the shoulder, that is clear of fixed objects; and (b) the lateral slope of the embankment. The design guidelines currently used for 3R projects provide for a 18 foot wide clear zone, which is considerably narrower than the 40 foot width now specified for new construction or reconstruction projects and the 30 foot width used prior to 1970. The slope of the embankment is typically not flattened in 3R projects unless the roadway is widened. Therefore, the policy of principal interest in this study is the width of the clear zone itself.

The general framework for the analysis consists of the minimization of a total cost function with respect to a set of a variables representing the roadside configuration. This cost function is simply the sum of the construction costs of roadside improvements and the cost of those accidents

whose occurrence is affected, in terms of frequency and severity, by the characteristics of the roadside. The geometric characteristics defining alternative roadside design policies observed in practice consist of only a limited number of values; therefore, the minimization of the total cost function actually reduces to a comparison of values corresponding to a few discrete points. A detailed definition of the total cost function, including secondary costs, such as maintenance costs, was not possible in this study because of the lack of data and the difficulty of relating these costs to the roadside design; however, it seems reasonable to assume their contribution would not change significantly the conclusions of the analysis.

The type of accident considered in this study as an indicator of the effect of roadside characteristics on safety is the single-vehicle, run-off-road (SVROR) accident. The number and severity of reported SVROR accidents may be regarded as a general indicator of the performance of the roadside in enabling vehicles that leave the roadway to avoid a collision or overturning. Of course, the roadside characteristics do not determine how many vehicles leave the roadway. This number is a function of roadway, environmental and vehicle-driver characteristics. A roadside that is completely safe would allow all vehicles that left the roadway to come to rest safely. Therefore, the number of SVROR accidents reported is a suitable measure of roadside performance. On-road accidents are excluded because it is unreasonable to presume a causal relationship exists between roadside characteristics and accidents in which the vehicle does not leave the roadway. Multiple-vehicle, run-off-road (MVROR) accidents are also excluded since these crashes generally involve vehicles rather than roadside features; the frequency of MVROR accidents is also considerably lower than for SVROR accidents.

The research design developed to explore the empirical relationship between accident frequency and severity versus roadside characteristics is a multi-faceted one, which was based on a careful review of the literature; see Appendix 1. Several studies were performed in parallel in order to explore the nature of the phenomena as fully as possible and to reduce the risk associated with devoting all the research resources to one approach.

Three preliminary studies were performed in an attempt to understand in more depth the nature of the accidents being studied. The first study is a macroscopic analysis of the importance of SVROR accidents relative to all accidents in Illinois for the years 1980-1985. The second study is a microscopic analysis based on responses to a questionnaire designed to determine the relative frequency and severity of run-off-road incidents. The third study is a statistical analysis of data for Illinois two-lane rural roads obtained from the National Cooperative Highway Research Program (NCHRP). These data provided the basis for structuring a research design for the more detailed analysis reported in Chapter 4. The findings from these three studies are described in Chapter 2.

In view of the focus of the overall study on the roadside clear zone, the research team concluded on the basis of the literature review, extensive discussions and some of the results of the preliminary studies that two types of analyses should be undertaken. The first, which may be described as microscopic, is based on a large sample of detailed investigations of individual accidents from the multidisciplinary accident investigation (MDAI) studies. A cross-section of over 300 accident records was extracted from this accident file. The principal objective of the cross-tabulations

performed on the data base extracted from these accident investigations is to determine the lateral distance actually traversed by vehicles leaving the roadway. Since most vehicles in the sample strike an object in the roadside before coming to rest, these analyses also enable one to understand in more depth how vehicles actually interact with roadside obstacles as well as to study the effects of vehicle speed and angle of encroachment on lateral distance traveled. These results are presented in Chapter 3.

Based on the analyses of the NCHRP data described in Chapter 2, a more detailed, macroscopic study of SVROR accident frequency and roadside characteristics was designed and carried out. A sample of 78 two-lane rural road segments in Illinois was selected and data collected. A statistical analysis was carried out in order to identify empirical relationships between accident frequency and various roadside characteristics including both clear zone width and lateral slope of the embankment, as well as average daily traffic and light condition. The findings of these analyses are presented in Chapter 4.

The final analysis of the entire study concerns the comparison of the costs of accident versus roadside improvements. Although the methodology of this benefit-cost analysis is straightforward, its execution was complicated by the difficulty of obtaining suitable data on the cost of removing roadside obstacles and the lack of statistically significant empirical relationships between reported accident frequency and roadside characteristics. Our interpretation of these findings, conclusions and recommendations for further studies are presented Chapter 5.

Chapter 2

Preliminary Analyses

In order to provide a better understanding of the problem under consideration and to complement and help interpret the results of the main analyses, three preliminary studies were conducted: (a) an aggregate analysis of accident data at a systemwide level to obtain a general picture of the characteristics of the SVROR accident occurrence and an estimate of its quantitative importance within the overall highway safety problem; (b) a questionnaire survey of run-off-road events and accidents to provide an estimate of the exposure to SVROR accidents (frequency of excursion onto the shoulder or the roadside area) and a detailed characterization of those events resulting in an encroachment into the roadside area, both in terms of the description of the excursion and the associated road-environment vehicle-driver characteristics; (c) an analysis of NCHRP data for Illinois road segments to explore suitable statistic methods and to provide a basis for a more detailed study.

2.1 Analysis of Accident Data at a Systemwide Level

Accident data for the entire two-lane, rural Illinois highway system over the six year period, 1980 - 1985, were classified based on a selected set of variables; the classification layout is shown in Table 2.1. The mean number of accidents per year was computed for the most important categories to highlight the relative magnitudes of the different types of accident considered in the classification; see Table 2.2. The most significant results extracted from this analysis may be summarized as follows:

Table 2.1

Dimensions of a Comprehensive Accident Analysis

1.	vehicle type	cars, vans and pickups motorcycles other not stated
2.	location	on-road off-road
3.	vehicle involvement	single-vehicle multiple-vehicle other
4.	severity	fatal and injury property damage only
5.	roadside involvement	struck fixed object overturned other noncollision
6.	light condition	day night not stated
7.	pavement condition	dry wet not stated

Table 2.2

Mean Number of Accidents per Year on Two-Lane,

Rural Illinois Roads by Type and Vehicle, 1980-1985

type	cars, vans and pickups	motorcycles	other and not stated	total
all accidents	21080	445	2433	23958
on-road	15589	281	1927	17797
off-road	5491	164	506	6161
single-vehicle	5191	161	469	5821
multiple-vehicle	143	2	19	164
other	157	1	18	176
off-road, single-vehicle accidents				
fatal and injury	2346	146	168	2660
fixed object	1270	33	70	1373
overturned	559	73	67	699
noncollision	517	40	31	588
property damage only	2845	15	301	3161
fixed object	1701	3	137	1841
overturned	361	6	74	441
noncollision	783	6	90	879
total	5191	161	469	5821
fixed object	2971	36	207	3214
overturned	920	79	141	1140
noncollision	1300	46	121	1467

1. Off-road accidents represent 26% of the total accident occurrence for cars, 21% for other and not stated vehicle types, but 37% for motorcycles. In considering these values, however, it should be noted that the absolute importance of the accident experience of motorcycles is almost negligible as compared with that of cars.
2. An analysis of the severity of on-road accidents as compared with off-road accidents does not indicate any substantial differences. The percentage of fatal and injury accidents is only slightly higher for the off-road category; however, if one considers that the off-road accidents mainly involve single-vehicles, and therefore that property damage accidents are very likely to be heavily underreported, it could be concluded that the actual proportion of fatal and injury events is probably lower for the off-road than for the on-road category. Moreover, a comparative analysis of the severity distribution among different vehicle types shows, as expected, that the importance of fatal and injury crashes is much higher for motorcycles than for the remaining categories.
3. Collisions with fixed objects represent the most frequent type of SVROR accident for cars (about 57%), while the overturning accidents dominate the distribution of involvement types for motorcycles (49%).
4. An analysis of the frequency distributions according to light and pavement condition (not shown in Table 2.2) indicates, for cars, that darkness is a very important factor for SVROR accidents, while the wetness of the pavement appears less critical. For both variables, a meaningful interpretation of the relative frequencies must take into account that the level of exposure, in terms of vehicle-miles of

travel, is very likely to be lower by night than by day and under wet conditions than under dry conditions.

5. At a general level, a substantial stability over time is observed for the annual number of accidents and percentage distributions (not shown in Table 2.2). This stability seems to reflect that the time frame of the analysis is too short to reveal any long-term trends attributable to changes in driver behavior, vehicle characteristics or roadway and roadside design. Therefore, variations within the six year period may be considered as being essentially of a stochastic rather than structural nature.

2.2 A Survey of Run-off-road Events and Accidents

A questionnaire survey was administered to a sample of 222 drivers generally representative of the driving population of moderate size cities surrounded by a rural environment. Based on the number of miles driven by the subjects in the month preceding the survey and on the reported number of excursions onto the shoulder or the roadside area, the rates at which vehicles leave the roadway on two-lane roads were estimated to be 2,100 events per million vehicle-miles in daytime versus 2,200 events per million vehicle-miles at night; for four-lane roads, 1,500 events per million vehicle-miles were estimated in daytime versus 1,800 events per million vehicle-miles at night. The mean rate was 1,900 events per million vehicle-miles. (Because of the low frequency of events reported, the statistical significance of the differences in rates was not tested.)

The number of encroachments into the roadside area beyond the shoulder reported by the interviewees was 105 in the previous two years, corresponding to an overall rate of 21 events per million vehicle-miles. Of these

excursions, 70% occurred on two-lane roads and 30% on roads having four or more lanes. Based on other information obtained in the survey and taking into account, where possible, the estimated exposure under different road/environmental conditions and driver behavior, it is possible to draw the following conclusions:

1. The proportion of roadside excursions that are reported to the police and therefore enter the official accident records is very limited (about 4% in the survey sample). Even if this is attributed in part to the fact that many of these excursions do not result in appreciable damage to the vehicle and/or injuries of the occupants, it seems clear that reliance upon police reports results in a very substantial under-representation of the frequency of SVROR accidents. This finding also indicates that estimates of accident frequencies obtained from analyses having the fatal and injury events as dependent variables are likely to be more realistic than those provided by analyses of total accidents, since a higher proportion of fatal and injury accidents is reported.
2. The frequency of vehicles leaving the roadway is approximately 100 times greater than vehicles entering the roadside area beyond the shoulder. However, vehicles leaving the roadway are at risk of entering the roadside area and this survey provides some indication of the exposure to this type of event. In this respect, the data show that the risk is slightly greater on two-lane than on four-lane highways, and at night than in daytime.
3. The estimated lateral distances traveled from the edge of the pavement by encroaching vehicles, a question of primary interest to this study, were generally small: in 80% of the cases the lateral excursion was

less than 4 feet, and in 20% of the cases it was between 4 and 20 feet; in only one case was an excursion exceeding 10 feet reported. Even though a much larger sample size is needed in order to provide a more confident estimate of extreme excursions, this result suggests that very few vehicles can be expected to travel more than 20 feet off the pavement. The longitudinal distances of encroachment were also found to be relatively modest, with only 20% of them being more than 50 feet and none exceeding 300 feet.

4. The results of this survey also indicate a set of factors that appear to be causally related to the excursion of vehicles into the roadside area. Among these, the most significant appear to be the horizontal alignment of the road and the behavior of drivers (mainly excessive speed) and condition (inattention and fatigue).

5. The potential hazards (obstacles) to which the drivers were exposed in their excursions off the roadway were signs (22%), ditches and culverts (47%), and other objects such as trees, mailboxes, utility poles, and fences (31%).

2.3 Analysis of NCHRP Data for Illinois Two-Lane Roads

In reviewing past studies of the relationship of run-off-road accidents and two-lane rural roadside characteristics, we learned that Graham and Harwood (1982) had collected and statistically analyzed data for Illinois, Minnesota and Missouri. Through the cooperation of NCHRP and Midwest Research Institute, we obtained the Illinois subsample of road segment data for use in exploring which statistical methods and functional forms would be suitable for the analysis of data collected in the present research project.

This preliminary data analysis was also useful in the design of the data collection for the present research.

Graham and Harwood (1982, Appendix D) employed analysis of variance to test for the effect of roadside design on the accident rate, defined as the number of accidents per million vehicle-miles of travel. Although a statistically significant effect was found, this test does not result in a direct quantification of the magnitude of the effect. A related method, multivariate regression analysis on dummy variables, enables the analyst to estimate the magnitude of the effect of roadside design as well as to control for other variables such as segment length and average daily traffic (ADT). In this manner, one can also test for possible nonlinear effects of the latter explanatory variables. Moreover, the regression method readily allows for unequal numbers of segments of each roadside design.

The results reported below stem from an exploratory analysis of the Illinois subsample of the NCHRP data. Altogether, Midwest Research Institute collected data on 70 two-lane, rural road segments in Illinois; see Graham and Harwood (1982, Chapter 2 and Appendix C). The roadside data were obtained from construction plans and field observations. Based on the detailed data acquired, each road segment was classified into one of three types: generally 6:1 lateral slope with 30 foot clear zone; generally 4:1 lateral slope with 30 foot clear zone; and less than 4:1 lateral slope with less than 30 foot clear zone. Another characteristic was shoulder width; we classified the segments as follows: 2-4 feet; 5-7 feet; and 8-10 feet. Data on the roadway width were also available: 64 segments were 24 feet wide; 6 segments were 22 feet wide.

Data were also collected on the number of accidents by type (fatal, injury, and property damage only) from January 1, 1975 to December 31, 1979. The number of years of accident data for each segment ranged from one to five years. These data were used to compute the mean number of accidents per year for two classes of accidents: total accidents; fatal and injury accidents. The overall means by ADT, roadside policy and accident type are given in Table 2.3. These two dependent variables were regressed on the following explanatory variables: segment length; roadway width; shoulder width; ADT; and roadside design policy as defined above.

Each explanatory variable was represented as a continuous variable, except for the (0, 1) or dummy variables for roadway width, shoulder width and roadside design policy, which are defined as follows for each segment:

D_6 = 1, if generally 6:1 slope and 30 foot clear zone; 0, otherwise;

D_4 = 1, if generally 4:1 slope and 30 foot clear zone; 0, otherwise;

D_2 = 1, if less than 4:1 slope and less than 30 foot clear zone;
0, otherwise.

Since the sum of these three variables for each segment equals one by definition, these variables are linearly dependent implying that the regression coefficients cannot be estimated. For this reason, variable D_2 was omitted from the equation without loss of information. The resulting regression coefficients for D_6 and D_4 determine their effects relative to D_2. Given these estimates, it is then possible to calculate the effect of each roadside design policy relative to the mean. The statistical results are presented here in the latter form which we believe to be more intuitively meaningful.

Table 2.3

Arithmetic Mean Accident Frequencies by ADT,

Roadside Policy And Accident Type for Illinois Subsample

ADT	Type	Policy (mean accidents/mile) no clear zone	4:1 clear zone	6:1 clear zone
≤3,000	Total	1.234	0.544	0.236
	Fatal and Injury	0.427	0.200	0.071
>3,000	Total	1.818	0.586	0.515
	Fatal and Injury	0.803	0.282	0.211

Source: Graham and Harwood (1982) project data

Two forms of the regression equation are considered. The first hypothesizes that the dependent variable y is a linear function of the explanatory variables x_1, x_2, ...; a linear hypothesis is the simplest plausible relationship.

$$y = a + b_1x_1 + b_2x_2 + \ldots$$

The parameters b_1, b_2, ... are the slopes of the linear function estimated from the data. The intercept term by definition is simply

$$a = \bar{y} - b_1\bar{x}_1 - b_2\bar{x}_2 - \ldots$$

where the bar denotes the arithmetic mean; for example; for the dependent variable,

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i$$

where i denotes the ith road segment. Rearranging terms, one obtains

$$y = \bar{y} + b_1(x_1 - \bar{x}_1) + b_2(x_2 - \bar{x}_2) + \ldots$$

A second hypothesis is that y is a multiplicative function of x_1, x_2,...

$$y = a(x_1)^{b_1}(x_2)^{b_2} \ldots$$

Such a hypothesis may be estimated by taking natural logarithms:

$$\ln(y) = a + b_1\ln(x_1) + b_2\ln(x_2) + \ldots$$

Again the regression coefficients b_1, b_2 ... are estimated from the data. As above, the intercept term may be defined in terms of the variable means:

$$a = \overline{\ln(y)} - b_1\overline{\ln(x_1)} - b_2\overline{\ln(x_2)} - \ldots,$$ resulting in

$$\ln(y) = \overline{\ln(y)} + b_1(\ln(x_1) - \overline{\ln(x_1)}) + b_2(\ln(x_2) - \overline{\ln(x_2)}) + \ldots$$

This expression can be represented more directly by exponentiating, or taking antilogarithms, resulting in

$$y = \bar{y}(x_1/\bar{x}_1)^{b_1}(x_2/\bar{x}_2)^{b_2} \ldots$$

In this case, however, the means, $\bar{y}$, $\bar{x}_1$, $\bar{x}_2, \ldots$, are geometric means; for example, for the dependent variable,

$$\bar{y} = \exp\left(\frac{1}{n}\sum_{i=1}^{n} \ln(y_i)\right) = \left(\prod_{i=1}^{n} y_i\right)^{1/n}$$

Typically, the values of the geometric and arithmetic means are similar.

These two regression models or hypotheses were estimated for three definitions of the accident variable: mean number of accidents per year; mean number of accidents per year per mile, or accident frequency; and mean number of accidents per year per million vehicle-miles, or accident rate. Because of the close relationship of these variables, one would expect to obtain consistent and similar results. An advantage of the number of accidents or accident frequency model is that possible nonlinear effects of ADT can be considered.

2.3.1 Linear Models

The first linear models are for mean number of total accidents per year, A_t, and the mean number of fatal and injury accidents per year, A_{fi}, as a function of road segment length in miles, L, average daily traffic in 1,000s of vehicles/day, T, and roadside design policy. The equations are:

$$A_t = 4.83 + 0.94(L - 4.77) + 0.87(T - 3.32) - 2.59D_6 - 2.33D_4 + 2.38D_2$$

$$A_{fi} = 1.89 + 0.33(L - 4.77) + 0.42(T - 3.32) - 1.00D_6 - 0.88D_4 + 0.91D_2$$

All coefficients in both equations are statistically significant and the signs are as one would expect. The values of R^2 are 0.53 and 0.50 respectively. These models were estimated on all 70 road segments including some segments with zero accidents. Note that the effects of roadside design categories D_6 and D_4 are very similar as compared with D_2.

The above equations may be simplified by standardizing the number of accidents by segment length, L, and omitting this variable as an explanatory variable. This modification should reduce the goodness-of-fit, as measured by R^2, since the statistical association with L is not expected to be entirely removed by the standardization operation. The resulting equations for mean number of accidents per year per mile, F, are as follows:

$$F_t = 1.01 + 0.20(T - 3.32) - 0.59D_6 - 0.38D_4 + 0.51D_2$$

$$F_{fi} = 0.41 + 0.13(T - 3.32) - 0.24D_6 - 0.13D_4 + 0.20D_2$$

All coefficients in both equations are statistically significant and the signs are as expected. The R^2 values are 0.36 and 0.34, which are substantially lower.

These equations can be simplified further by standardizing the accident frequency by ADT resulting in the mean number of accidents per year per million vehicle-miles, R, as follows:

$$R_t = 85.7 - 8.3(T - 3.32) - 51.6D_6 - 35.5D_4 + 45.0D_2$$

$$R_{fi} = 33.2 - 0.2(T - 3.32) - 20.8D_6 - 11.4D_4 + 17.5D_2$$

In these equations only the coefficients for D_6, D_4 and D_2 are statistically significant. The statistical significance of ADT has been effectively removed from these linear equations by standardizing the dependent variable. The R^2 values for these equations are 0.37 and 0.32, which are very similar to the accident frequency equations. The effects of roadway width and shoulder width were tested for several of the equations, but in no case were they significant.

These six equations exhibit a moderately strong statistical correlation between the accident indicators and the explanatory variables. The linear form of the functions, however, is rather implausible; one would expect the

effect of roadside design to affect the accident variables in a proportional or multiplicative manner rather than as an additive effect. Having tested the simple linear hypothesis, we now turn to the results for this more plausible multiplicative model.

2.3.2 Multiplicative Models

The first multiplicative models are for the mean annual number of accidents per year, A, as a function of road length in miles, L, average daily traffic in 1,000s, T, and roadside design policy. The equations are:

$$A_t = 2.85(L/3.88)^{0.99}(T/3.10)^{0.69}(0.47)^{D6}(0.68)^{D4}(1.82)^{D2}$$

$$A_{fi} = 1.39(L/4.14)^{0.93}(T/3.15)^{0.90}(0.51)^{D6}(0.65)^{D4}(1.58)^{D2}$$

The above models were estimated only for the subsample consisting of segments with one or more accidents of the type indicated. The values of R^2 are 0.78 and 0.66; although these values are higher than for the corresponding linear model, these magnitudes are not directly comparable. A log linear model generally has a higher R^2 than a linear model.

In the above equations, the effect of segment length is essentially linear and statistically significant. In the total accidents model, the effect of ADT is proportional to the two-thirds power of ADT, which is substantially less than linear. This indicates that the relationship of the total number of accidents to ADT is increasing at a decreasing rate. The effects of roadside slope and clear zone are statistically significant and substantial in the two equations; however, the effect on fatal and injury accidents is slightly less than for total accidents.

The above equations may be simplified by standardizing with regard to segment length, L. We should expect that this operation should reduce the goodness-of-fit, as measured by R^2, since there is one less variable and the

coefficient for L was not exactly 1.0. The resulting equations for accident frequency, F, are as follows:

$$F_t = 0.74(T/3.10)^{0.70}(0.47)^{D6}(0.68)^{D4}(1.82)^{D2}$$

$$F_{fi} = 0.34(T/3.15)^{0.94}(0.51)^{D6}(0.65)^{D4}(1.58)^{D2}$$

As can be seen, the coefficients for ADT and roadside design are remarkably similar to those for the previous equations. These coefficients are again statistically significant; the values of R^2 are 0.64 and 0.53.

The effect of ADT can be simplified by standardization and omitting the variable from the equation. Since the exponent of ADT is substantially different from 1.0, this operation may affect the magnitudes of the roadside coefficients; however, as shown below the roadside coefficients are nearly unchanged:

$$R_t = 65.1(0.48)^{D6}(0.70)^{D4}(1.80)^{D2}$$

$$R_{fi} = 29.1(0.51)^{D6}(0.66)^{D4}(1.58)^{D2}$$

(The comparable equations with T included are exactly the same as for accident frequency except that the coefficient of T is reduced by 1.0.) These equations are also statistically significant; the R^2 values are 0.58 and 0.44. For some of the models the effects of road width and shoulder width were also tested. In no cases were these variables statistically significant.

2.3.3 Conclusions

Judged both in terms of the estimated functional forms and the goodness-of-fit (R^2), it is evident that the multiplicative models are superior. Accordingly, only multiplicative models are tested with the data collected in this research project, as reported in Chapter 4.

A comparison of the three dependent variable definitions raises interesting questions about the functional form of segment length and ADT. The effect of length appears to be highly linear in the NCHRP data. To the contrary, the effect of ADT is nonlinear. This result raises a question concerning how to represent ADT in the statistical analysis. The approach which makes the least commitment to a functional form is to represent each ADT interval by a dummy variable. The resulting coefficients then determine the function. Since there is considerable interest in this research project in identifying a roadside policy which is ADT specific, we decided to adopt the dummy variable approach using intervals of 1,000 vehicles/day to define each class.

Chapter 3

Microscopic Analyses of Roadside Excursions of Single Vehicle Accidents

3.1 Introduction

The multidisciplinary accident investigation (MDAI) data are the result of intensive accident investigations by multidisciplinary teams. The crashes investigated generally produced some degree of injury or a fatality to the occupants of the vehicles. In this respect, they are not representative of all highway crashes. In addition, MDAI teams were selective in the types of crashes that they investigated; primary thrusts in the investigations were to evaluate the effectiveness of restraint systems, collapsible steering columns, and the general protective capabilities of various vehicle design features.

The MDAI computerized data files were searched for cases involving vehicles which ran off the road on two lane highways. Data for 1372 such cases were available. The distribution of these cases is shown in Table 3.1 indicating the proportion that occurred by roadway conditions: dry-wet, tangent-curved, level-sloping, and day-night. In order to obtain an indication of the types of conditions that can be expected in a representative set of accident data, an analysis was made of accident data collected by the National Accident Sampling System (NASS) in 1984. These data provided a total of 1080 accidents in which a vehicle ran off a two-lane highway without striking a guardrail. Table 3.1 also shows the distribution of those accidents.

By comparing the proportion of each condition in which an accident occurred for the MDAI and the NASS data, the degree to which the MDAI sample

Table 3.1

Distribution of 1984 NASS and MDAI

Two Lane, Rural, Single-Vehicle Roadside Crashes

Condition				Percent of Cases*	
Pavement Surface	Horizontal Alignment	Vertical Alignment	Ambient Lighting	NASS[1]	MDAI[2]
Dry	Tangent	Level	Day	10.4	9.8
Wet	Tangent	Level	Day	5.0	4.8
Dry	Curve	Level	Day	4.5	4.0
Wet	Curve	Level	Day	1.6	1.5
Dry	Tangent	Slope	Day	5.8	3.8
Wet	Tangent	Slope	Day	3.5	1.3
Dry	Curve	Slope	Day	5.2	3.7
Wet	Curve	Slope	Day	3.5	2.7
Dry	Tangent	Level	Night	16.3	15.7
Wet	Tangent	Level	Night	6.3	10.1
Dry	Curve	Level	Night	9.8	13.2
Wet	Curve	Level	Night	4.0	5.8
Dry	Tangent	Slope	Night	6.7	6.3
Wet	Tangent	Slope	Night	3.1	3.6
Dry	Curve	Slope	Night	9.9	9.6
Wet	Curve	Slope	Night	4.3	4.4
Number of cases				1080	1372

*Cases involving vehicles striking guardrails were excluded.

1) National Accident Sampling System for 1984
2) Multidisciplinary Accident Investigations from 1968 to 1978.

is representative of the conditions in which crashes occurred in 1984 can be seen. It will be noted that the distributions of these two sets of data are quite similar, with a few exceptions, showing that the MDAI two-lane, rural, single-vehicle crashes are quite representative of the National Accident Sampling System findings. It must be remembered, however, that the MDAI crashes are undoubtedly not representative in terms of crash severity.

Table 3.2 shows the distribution of two-lane, rural, single-vehicle accidents in the 1984 NASS data file according to some major environmental and roadway conditions. The table shows that 69% of the accidents occurred on dry roads and 31% on wet roads. Since there is precipitation in the Midwest on about 19% of days, these data show that relatively more single-vehicle crashes occurred on wet roadways. Similarly, the data also show that 43% of the single-vehicle crashes occurred on curves. Since curves represent much less than 43% of the roadway mileage, single-vehicle accidents were overrepresented on curves as compared with tangent segments. The data also show that 60% of the accidents occurred at night, indicating a clear overinvolvement of crashes during nighttime driving conditions. In addition, 42% of the accidents occurred on either an up or downgrade, again suggesting that grade was a factor in single-vehicle accidents. The general trends in the MDAI data are similar.

A subset of the 1,372 MDAI cases involving single-vehicle crashes was selected consisting of between 9 and 35 cases represented by each of the combinations of the four conditions shown in Table 3.1. The purpose was not to obtain a representative sampling of cases, as in the NASS data, but to obtain a subsample of each of the 16 conditions to the extent that they were available in the MDAI file.

Table 3.2

Summary of Conditions for Two-Lane, Rural, Single-Vehicle Roadside Crashes for the 1984 NASS, MDAI and MDAI Sample Data

Condition	NASS[1]	MDAI[2]	MDAI Sample
Pavement Surface			
Wet	31.3	33.9	37.3
Dry	68.7	66.1	62.7
Horizontal Alignment			
Tangent	57.1	55.4	45.1
Curve	42.9	44.6	54.9
Vertical Alignment			
Level	57.8	64.9	48.9
Sloping	42.2	35.1	51.1
Ambient Lighting			
Day	39.6	31.0	48.9
Night	60.4	69.0	51.1
Number of cases	1080	1372	328

1) National Accident Sampling System for 1984
2) Multidisciplinary Accident Investigations from 1968 to 1978.

A copy of those sections of the accident report describing the pre-crash phase of the accident was obtained for each of the MDAI cases. A coding form was developed for tabulating the data from each case in terms of the road conditions, roadside characteristics, the distance that the vehicle ran off the road, the direction taken by the vehicle, information about the driver's experience and familiarity with the area and the vehicle, and an estimate of the damage repair cost.

The main purpose of obtaining the MDAI data was to obtain sufficient detail, which is not commonly available from police reports, about precrash aspects of the accident, the distances that the vehicle traveled along the roadside longitudinally and laterally, the kind of objects that were found in the roadside area in the vicinity of the location where the vehicle left the road, and the objects that the vehicle struck.

3.2 Overall Findings

The distributions of the variables describing the conditions in which the sampled crashes occurred are shown in Tables 3.3 and 3.4. Table 3.3 describes various roadway and roadside characteristics of the MDAI sample. Although the accident reports were requested for two lane, rural roads, the table indicates some possible discrepancies, as shown by the distribution of roadway width and posted speed limit. Table 3.4 describes characteristics of drivers, vehicles and the excursions into the roadside.

The data show that 50% of the furthest objects struck in the sample were within 14 feet of the edge of pavement and that 50% of the vehicles came to rest within 15 feet of the edge of the pavement; see also Table 3.4(f). These findings, together with those on objects in the roadside shown in Table 3.3 (d,f), suggest that objects in the roadside such as

Table 3.3

Roadway and Roadside Characteristics of Crashes in the MDAI Sample

a) Roadway Width

0-20 feet	41%
21-24	40
> 24	19

b) Shoulder Width

0-4 feet	48%
> 4	52

c) Roadside Width Beyond Shoulder

0- 5 feet	11%
6-10	8
11-30	18
not available	63

(N=122)

d) Lateral Distance from Pavement to Nearest Object*

0- 8 feet	50%
9-13	25
14-30	20
> 30	5

e) Lateral Distance from Pavement to Lowest Point*

0- 6 feet	50%
7-14	25
15-24	15
> 24	10

(N=90)

f) Objects in the Roadside*

	All	Struck
signs	12%	5%
trees	24	25
utility poles	20	13
fences	8	15
ditch/culvert	17	23
mailbox	5	4
other	14	15

g) Posted Speed Limit

0-30 mph	17%
31-40	19
41-50	16
> 50	48

* in the vicinity where the vehicle left the roadway

Table 3.4

Vehicle and Driver Characteristics of Crashes in the MDAI Sample

a) Vehicle Type

auto	82%
pick-up, van	11
trucks, buses	7

b) Driver Characteristics

median years driving - 7 years

median miles driven/year - 11,500 miles

mean number of previous accidents - 0.4/driver

mean number of previous violations - 0.5/driver

familiar with area - 85%

familiar with vehicle - 73%

c) Speed Just Prior to Accident

≤ 30 mph	20%
31-40	24
41-50	22
51-60	16
> 60	18

d) Side Vehicle Left Road

Right	62%
Left	38

e) Angle Vehicle Left Roadway

0- 5 degrees	7%
6-25	56
26-35	12
36-45	16
> 45	9

f) Lateral Distance from Pavement

	Furthest Object Struck	Resting Place Of Vehicle
0-10 feet	30%	26%
11-20	40	30
21-30	15	17
31-40	10	12
41-50	3	6
> 50	2	9
maximum	78 feet	93 feet

g) Longitudinal Distance Traveled After Leaving the Pavement

0- 49 feet	25%
50- 98	25
99-156	25
156-250	15
> 250	10
maximum	656 feet

ditches or culverts, and mailboxes may be involved in a substantial number of crashes. This aspect is explored in more detail in the next section.

3.3 Effects of Striking an Object on Lateral Distance to Final Resting Place

In 293 of the 328 cases the vehicle left the roadway and struck an object, such as a tree, utility pole, fence, sign, ditch or culvert, mailbox or some other object. Since such collisions have an effect upon the maximum lateral distance that would have been traveled by the vehicles, an analysis was also made of those cases where major objects such as trees, utility poles or fences were not struck. There were only 39 cases in the latter category. Two distributions were obtained on tangents and curves of the lateral distances traveled by the vehicles to their final resting position from the edge of the roadway; in one an object was struck, and in the other a significant object was not struck.

For vehicles leaving the road on tangent segments, the median lateral distance from the pavement for vehicles that struck an object was 16 feet; for those that did not strike an object, it was 20 feet. For vehicles leaving the road on curves, the median distance was 17 feet for those that struck on object, and 24 feet for those which did not strike an object. These results are shown in the cumulative percent distributions in Figures 3.1 and 3.2 for tangents and curves respectively. Figure 3.3 shows the lateral distances for tangents and curves combined, when objects were struck and not struck. Combining the tangent and curve data is reasonable because of their similarity. Despite the lateral distances traveled by vehicles being affected by striking objects, it is not possible to perform further analyses using only data in which objects were not struck, because there are too few cases available for such analyses.

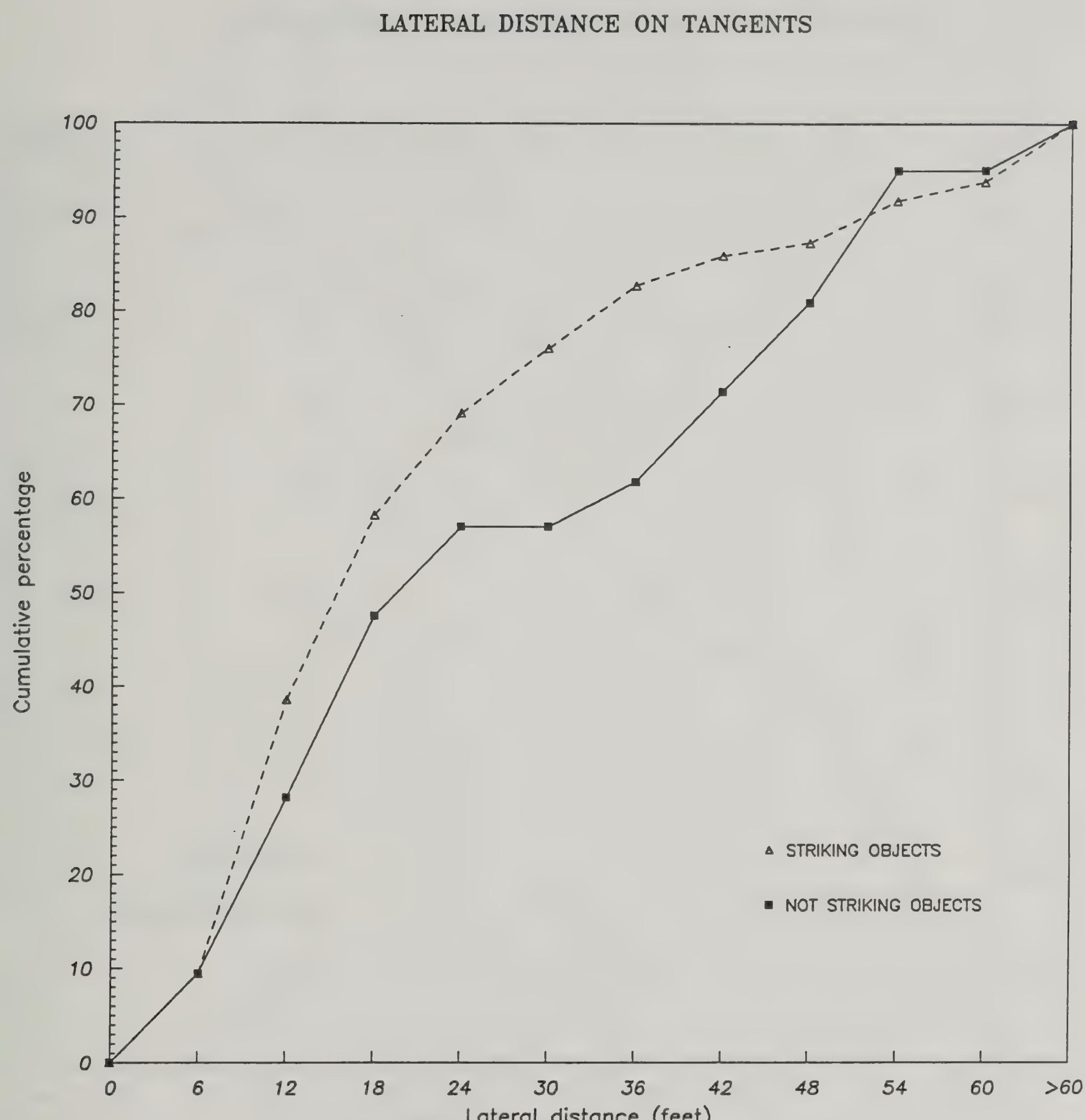

Figure 3.1: Cumulative distributions of vehicles leaving the road on tangents, striking and not striking objects in the roadside, vs. lateral distance from the edge of the pavement to the final resting place

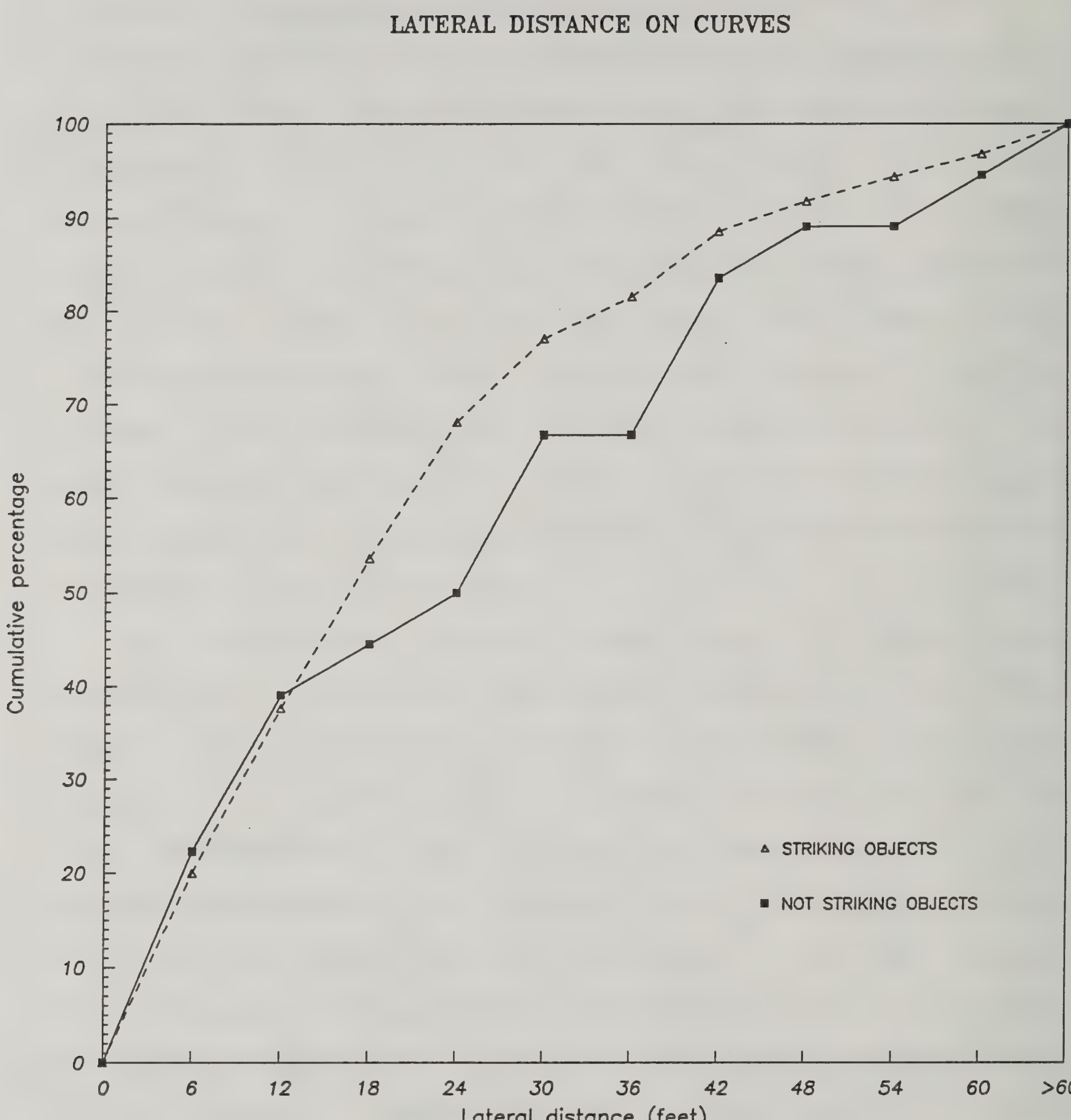

Figure 3.2: Cumulative distributions of vehicles leaving the road on curves, striking and not striking objects in the roadside, vs. lateral distance from the edge of the pavement to the final resting place

MEAN LATERAL DISTANCE ON TANGENTS AND CURVES

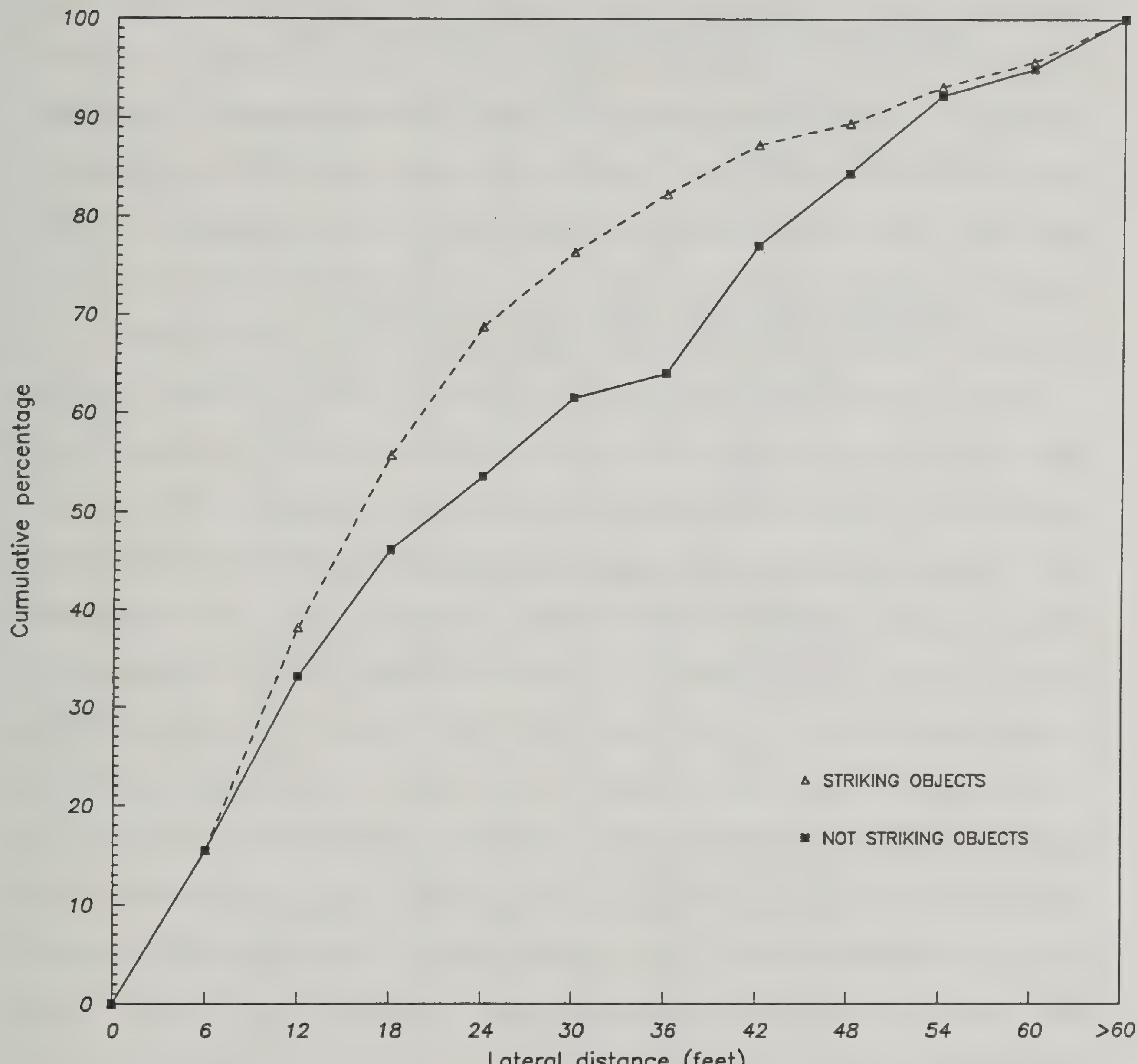

Figure 3.3: Mean cumulative distributions of vehicles leaving the road on tangents and curves, striking and not striking objects in the roadside, vs. lateral distance from the edge of the pavement to the final resting place

3.4 Lateral Distance from Edge of Pavement to Final Resting Place

The interactive effects upon the lateral distance traveled by a vehicle from the pavement to its final resting place as a function of pre-crash speed and roadway and other variables are next considered. Table 3.5(a) shows the effects of speed on tangent and curved segments on lateral distance. In this table the vehicle's speed has been reduced to a two-level factor in which speeds below 50 mph and those more than 50 mph are compared. Similarly, the lateral distance distribution has been aggregated to three levels by considering cases in which the lateral distance was 18 feet or less, 19 to 30 feet, or more than 30 feet from the edge of the roadway.

Table 3.5(a) shows for speeds of 50 mph or less on tangent segments that 74% of the vehicles came to rest within 18 feet of the edge of the pavement; for those traveling more than 50 mph on tangents, 39% came to a stop within 18 feet of the edge of the pavement, while 39% stopped at a lateral distance of more than 30 feet. The table also shows analogous results for the lateral distances at which vehicles leaving the pavement on curves came to rest. In this case 59% of the vehicles traveling at 50 mph or less came to rest within 18 feet of the edge of the pavement, while for those traveling more than 50 mph, 48% came to rest within 18 feet of the edge of the pavement. Therefore, on both tangent and curved segments, the vehicles traveling at more than 50 mph came to rest at greater distances than those traveling at less than 50 mph. However, this difference was statistically significant only on the tangent segments although the trend is the same on curves.

Table 3.5(b) shows the distributions of lateral distances by precrash speed by day and night. In this case the differences in lateral distances in daytime for speeds less than and more than 50 mph are quite minor.

Table 3.5

Percent of Vehicles at Final Resting Place Classified by Speed, Alignment, Lighting, Pavement Surface and Angle of Departure

(a) Lateral Distance by Speed and Horizontal Alignment

	Lateral Distance (feet)				Horizontal
Speed(mph)	≤18	19-30	>30	Total	Alignment
≤50	74	16	10	66	Tangent ($p < .01$)
>50	39	22	39	34	
≤50	59	25	16	63	Curve
>50	48	23	29	37	

(b) Lateral Distance by Speed and Ambient Lighting

	Lateral Distance (feet)				Ambient
Speed(mph)	≤18	19-30	>30	Total	Lighting
≤50	64	21	15	74	Day
>50	62	21	17	26	
≤50	69	20	11	56	Night ($p < .01$)
>50	35	24	41	44	

(c) Lateral Distance by Speed and Vertical Alignment

	Lateral Distance (feet)				Vertical
Speed(mph)	≤18	19-30	>30	Total	Alignment
≤50	69	17	14	63	Level ($p < .01$)
>50	38	21	41	37	
≤50	63	24	13	65	Slope
>50	50	24	26	35	

(d) Lateral Distance by Speed and Pavement Surface

	Lateral Distance (feet)				Pavement
Speed(mph)	≤18	19-30	>30	Total	Surface
≤50	69	20	11	57	Dry ($p < .01$)
>50	39	25	36	43	
≤50	63	21	16	77	Wet
>50	60	15	25	23	

(e) Lateral Distance by Angle of Departure

	Lateral Distance (feet)			
Angle(deg)	≤18	19-30	>30	Total
≤25	68	59	56	64
>25	32	41	44	36

Table 3.6

Percent of Vehicles at Final Resting Place

by Horizontal Alignment and Ambient Light

Lateral Distance (feet)	Curve		Tangent	
	Day	Night	Day	Night
≤ 18	69	57	60	51
19-30	19	17	23	25
> 30	12	26	17	24

However, at night the vehicles traveling more than 50 mph came to rest at significantly greater lateral distances from the edge of the pavement than those traveling at 50 mph or less. This is shown by the fact that 31% of vehicles traveling 50 mph or less came to rest at more than 18 feet from the edge of the pavement, whereas 65% of vehicles traveling more than 50 mph came to rest at more than 18 feet from the edge of the pavement.

Table 3.5(c) shows analogous data for the effects of speed and roadway grade upon the lateral distance distribution. It is seen that 31% of vehicles traveling at 50 mph or less came to rest at more than 18 feet from the edge of the pavement, whereas 62% of vehicles traveling at 50 mph or more came to rest at more than 18 feet from the pavement edge when the roadway was level; this difference is statistically significant ($p < .01$). On a road with a slope the trends were similar, showing the effect of greater speed, but the results were not significant.

Table 3.5(d) shows that on a dry pavement, 31% of vehicles traveling at 50 mph or less had lateral excursions of more than 18 feet compared with 61% of vehicles that were traveling at more than 50 mph. This difference is also statistically significant ($p < .01$). On wet roads these trends were not as clear and were not statistically significant. Table 3.5(e) shows that there is a positive association between the angle that the vehicle departed the roadway and the lateral distance to its final resting place. This association was found to be significant ($p < .05$) only when comparing vehicles which traveled more than 30 feet from the edge of the road with the remainder.

Table 3.6 shows the percent distribution to the final resting place of vehicles that left the road on tangents vs. curves in daytime vs. nighttime by lateral distance from the road. For example, 69%, 19% and 12% of

vehicles which left the road in daytime on tangents traveled up to 18 feet, 19-30 feet and more than 30 feet from of the pavement respectively. On both tangents and curves a greater proportion of vehicles traveled more than 30 feet at night than in the day. About the same proportions of vehicles traveled 19-30 feet in the day and night on tangents and curves. In daytime a greater proportion of vehicles traveled 18 feet or less than at night.

3.5 Conclusions

These analyses show that vehicles with speeds above 50 mph traveled further into the clear zone than vehicles with lower speeds. The effect of speed on lateral distance traveled was more marked on tangents than on curves, at night than in day, on level roads than on grades, and on dry than on wet pavements. The effect of departure angle on distance traveled was greater for angles of more than 25 degrees.

Taking into account that the accident rate at night is about three times that in the daytime, and also taking account of the number of cases in the MDAI sample which occurred at night and in the day, allowed the expected frequencies of cases in the day and night by lateral distance to be estimated. A chi-square test showed that the frequencies of excursions into the clear zone were significantly greater at night than in the day on tangents and on curves, and the distances traveled into the roadside were also greater at night than in the day. Therefore, excursions into the clear zone are a significant nighttime problem on both tangents and curves.

Chapter 4

Macroscopic Analyses of Reported Accidents and Roadside Characteristics

4.1 Data Collection

The data base used for the estimation of the models presented in this chapter consists of two categories of data that are described separately in this section.

4.1.1 Roadway and Roadside Data

A set of geometric and traffic characteristics expected to be useful in explaining single-vehicle, run-off-road accident occurrence on two-lane rural highways was identified in the preliminary analysis described in Section 2.3. Based on these results, the data collection was designed so as to allow for consideration of a broader and more detailed set of variables.

The roadway and roadside characteristics selected for inclusion in the data base were the length of the road segment, the width of the pavement, the width of the shoulder, the average daily traffic volume (ADT), the horizontal alignment, the lateral slope of the roadside, the width of the clear zone, and the presence of fixed objects along the roadside. For a more detailed definition of these variables, see Table 4.1.

The initial phase of the actual data collection process consisted of a screening of the IDOT two-lane, non-municipal highways inventory for the purpose of establishing a suitable base for the selection of the sample. From the original inventory, 517 segments were identified that had not undergone major construction-reconstruction in the last six years, the period for which accident data were available. Other criteria adopted in the selection of the sample were the consistency of roadway and shoulder

width within a segment, a posted speed limit of 55 mph, and a length of at least four miles. A broad range of ADT values was represented in this sample.

Data on roadside characteristics and horizontal alignment of these segments were subsequently obtained using the latest available construction plans. Typically, construction plans were available for only a portion of the segment initially identified. In the cases where the latest construction plan contained little or no information on roadside geometry and curves, a prior construction plan for the same segment was used. In the initial sample, segments with usable roadside/horizontal alignment data were found at a rate of approximately one out of six. This yielded a final sample of 78 segments. The size of the resulting sample was heavily constrained by the availability of roadside data; in many cases only partial data could be extracted.

The accuracy of the roadside information may be questionable since the data were obtained by manually reading the construction plans. The serious limitations encountered in this phase of the data collection clearly point to the need to incorporate roadside and horizontal alignment information into the highway inventory data base. However, despite the incompleteness and inaccuracy of this part of the data, a satisfactory stratification with respect to the relevant variables was obtained in the final sample.

The actual measurement of the roadside characteristics from the construction plans was carried out by sampling the values at intervals of 1,000 or 2,000 feet. The slope of the roadside and the width of the clear zone were measured on the cross-sections, while the number and lateral distance of the fixed objects were derived from the overhead plans for a

length of 200 feet on either side of a measurement point. The fixed objects were further classified into occasional objects (e.g. trees) vs. continuous or regular objects (e.g. fences, utility poles), in order to make explicit the potential differences between the two categories of obstacles with regard to probability of collision and cost of relocation. The data on ADT, roadside characteristics and horizontal alignment were aggregated into discrete categories and extrapolated to estimate the characteristics of the entire segment.

A category representing the proportion of segment length with missing data on a given variable was added, where necessary, in order to avoid reducing the length of some segments with incomplete data. The rationale for considering the proportion of missing data as a variable in the accident model is that the estimates of the regression coefficients for the observed variables should not be distorted by the missing data; such distortion could occur if the observed data were extrapolated to the missing portions. The complete list of roadway and roadside variables considered in the analysis is given in Table 4.1, together with the corresponding sample means and standard deviations.

4.1.2 Accident Data

Accident data for the sample of 78 two-lane rural roads were retrieved from the IDOT accident file. A period of six calendar years (1980 - 1985) was considered in order to reduce the influence of the variation of SVROR accident frequencies over time, and thereby ensure sufficient statistical reliability of the resulting average values. All the accidents whose location corresponded to some particular feature of the roadway (such as a bridge, an overpass, or an intersection) were excluded since it is not

Table 4.1

Variables, Means and Standard Deviations of Road Characteristics

Variable	Mean	Std.Dev.
Length of segment (miles)	5.70	2.30
Roadway width (ft)	23.15	2.10
Shoulder width (ft)	7.76	2.38
Percent of length with ADT < 1,000 vehicles/day	17.56	35.06
Percent of length with ADT 1,000-2,000 vehicles/day	38.22	43.78
Percent of length with ADT 2,000-3,000 vehicles/day	20.35	35.95
Percent of length with ADT 3,000-4,000 vehicles/day	11.87	28.75
Percent of length with ADT > 4,000 vehicles/day	11.95	31.18
Percent of length tangent	61.74	38.29
Percent of length curved with R > 10,000 ft	2.54	4.45
Percent of length curved with 3,000 ≤ R ≤ 10,000 ft	4.59	10.52
Percent of length curved with R < 3,000 ft	5.49	9.18
Percent of length with missing curve data	25.64	43.95
Percent of length with roadside slope 2:1 or steeper	9.05	19.20
Percent of length with roadside slope 3:1	15.42	24.30
Percent of length with roadside slope 4:1	15.60	24.84
Percent of length with roadside slope 5:1 or flatter	19.47	32.84
Percent of length with missing slope data	40.46	46.50
Percent of length with clear zone width 3-9 ft	0.51	1.73
Percent of length with clear zone width 10-15 ft	5.15	13.26
Percent of length with clear zone width 16-21 ft	12.13	20.19
Percent of length with clear zone width 22-27 ft	13.95	21.82
Percent of length with clear zone width 28 ft or more	27.90	36.23
Percent of length with missing clear zone width data	40.36	46.23
Percent of length with cont./reg. objects 3-9 ft	1.90	4.99
Percent of length with cont./reg. objects 10-15 ft	3.90	10.24
Percent of length with cont./reg. objects 16-21 ft	9.81	18.73
Percent of length with cont./reg. objects 22-27 ft	3.14	6.86
Percent of length with cont./reg. objects 28 ft or more	18.15	29.19
Percent of length with missing cont./reg. objects data	63.10	34.91
Percent of length with no occasional objects	37.47	29.28
Percent of length with occasional objects 3-9 ft	4.33	9.79
Percent of length with occasional objects 10-15 ft	8.53	11.30
Percent of length with occasional objects 16-21 ft	17.49	18.67
Percent of length with occasional objects 22-27 ft	8.13	14.17
Percent of length with occasional objects 28 ft or more	10.58	15.95
Percent of length with missing occasional objects data	13.47	32.83

Number of segments is 78.

reasonable to assume in such locations any relationship between accident occurrence and roadside characteristics.

The severity distribution for the entire sample indicates that 1.4% of the accidents were fatal, 44.5% were injury-producing, and 54.1% involved only property damage. The small number of fatal accidents prevented any separate analysis of this accident type. The most frequent type of involvement was found to be collision with a fixed object (48.6%), followed by other noncollision events (27.1%) and overturning (24.3%). The distribution of accidents by vehicle type is strongly dominated by cars, vans and pickups (88.5%), while motorcycles represent 3.7% and other vehicles 7.8%.

A set of variables representing environmental characteristics and human factors was considered for inclusion in the accident models. For these variables it was also decided to adopt a normalized format (percentage of accidents occurring on a given segment under a certain environmental condition). The variables considered are the pavement condition (dry/wet), the presence of defects in the road (defects/no defects), the light condition (day/night), the weather condition (clear/bad), and the driver condition (normal/not normal). By comparing the accidents on these segments with the NASS data in Table 3.2, it may be seen that similar percentages occur at night (53% vs. 60% for NASS) and on wet surfaces (40% vs. 31% for NASS); thus these data are fairly representative of all SVROR crashes.

Of the 78 segments in the sample, 71 had one or more accidents reported during the six year period and 64 had one or more accidents involving fatalities or injuries in the same period. The complete list of accident indicators and environmental conditions considered in the analysis is given in Table 4.2, together with the corresponding sample means and standard

Table 4.2

Variables, Means and Standard Deviations of Accident Characteristics

Variable	Mean	Std.Dev.
Number of total SVROR accidents (accidents/year)	1.72	1.71
Number of fatal and injury SVROR accidents (accidents/year)	0.78	0.81
Frequency of total SVROR accidents (accidents/mile/year)	0.30	0.26
Frequency of fatal and injury SVROR accidents (accidents/mile/year)	0.13	0.12
percent of accidents on dry surface	60.0	24.4
percent of accidents on wet surface	40.0	24.4
percent of accidents on roads with no defects	79.1	18.6
percent of accidents on deficient roads	20.9	18.6
percent of accidents in daytime	46.9	23.5
percent of accidents in nighttime	53.1	23.5
percent of accidents during clear weather	71.9	19.3
percent of accidents during bad weather	28.1	19.3
percent of accidents with driver in normal condition	69.3	26.2
percent of accidents with driver not in normal condition	30.8	26.2

Number of segments is 78.

deviations. Of the 78 segments, however, only 53 segments have roadside data for at least a portion of the segment; of these segments, five had no reported accidents during 1980-1985. These 53 segments are used for most of the statistical analyses reported below.

For the purpose of a preliminary examination of the relation of accident frequencies to roadside characteristics, each segment was classified into one of three broad categories if more than half of its length corresponded to one of the eight categories defined by the following criteria:

1. clear zone width: 3-15 feet vs. > 15 feet
2. side slope: $\geq$ 3:1 vs. < 3:1
3. average daily traffic: $\leq$ 3,000 vs. > 3,000

The mean number of accidents/mile for total accidents and fatal plus injury accidents is shown in Table 4.3. The number of cases is shown in parentheses after each mean value. There is no road segment with a roadside width > 15 feet and ADT > 3,000 for more than half of its length.

The mean values are generally decreasing with increasing roadside width and increasing with increasing slope and increasing ADT as expected. This classification does not effectively utilize, however, the detailed data collected for each segment; to exploit the date more fully, a detailed classification was developed as described in Section 4.2.

4.2 Statistical Analysis

This section describes the statistical analyses performed on the sample of road segments for the estimation of models relating accident occurrence to roadway, roadside and traffic characteristics and environmental conditions. This part of the study, within the general framework outlined in

Table 4.3

Arithmetic Mean Accident Frequencies by ADT, Roadside Characteristics and Accident Type

ADT	Type	Slope	Width (mean accidents/mile) 3-15 feet	>15 feet
≤3,000	Total	≥3:1	0.259 (2)	0.217 (14)
		<3:1	0.257 (1)	0.224 (21)
	Fatal and Injury	≥3:1	0.113 (2)	0.105 (14)
		<3:1	0.073 (1)	0.087 (21)
>3,000	Total	≥3:1	—	0.767 (5)
		<3:1	—	0.572 (9)
	Fatal and Injury	≥3:1	—	0.317 (5)
		<3:1	—	0.230 (9)

Number of segments in each class is shown in parentheses after the mean.

Chapter 1, seeks to provide a quantitative method for assessing the accident frequency corresponding to selected characteristics of the roadside design. After a brief outline of the methodology adopted, the remainder of the segment is devoted to the analysis of the different approaches explored in the model formulation.

4.2.1 Methodology

The statistical technique used in this analysis is multiple regression with dummy variables. The approach adopted here, however, differs from the usual integer (0,1) dummy variables technique, in that some of the independent variables are categorized by a fractional amount (%). This approach, hereafter referred to as the fractional dummy variables technique, is more general than the integer (0-1) technique, and improves the ability of the model to capture and represent in a meaningful fashion the inherent variability of some roadway/roadside characteristics within a road segment. This feature of the model allows a more intensive use of the detailed information gathered in the data collection phase. Fractional dummy variables retain the basic statistical properties of integer dummy variables.

The only variables that are treated as continuous in the following analyses are the accident indicators (dependent variables) and the length of the segment. Two variables, roadway width and shoulder width, that are uniform within each segment, are defined in the usual integer dummy variable format, while all the remaining independent variables (ADT, horizontal alignment, roadside characteristics and environmental/human factors) are handled as fractional dummies.

The accident indicators tested as dependent variables in the regression models are the Number of Accidents (accidents/year) and the Accident

Frequency (accidents/mile/year). This choice is based on the results of the statistical analysis carried out on the NCHRP data, which indicated the existence of a nonlinear relationship between either Number of Accidents or Accident Frequency and ADT. Such a relationship is obscured in a model defined on Accident Rate (accidents/vehicle-mile). Similarly, the length of the road segment is included only in the models for the Number of Accidents, since in the equations for Accident Frequency the dependent variable is standardized with respect to the length itself.

Finally, a word should be said about the structure of the models. In the analysis of the NCHRP data, the multiplicative form exhibited a substantially greater variance explanation as compared to the additive form, again because of the inherent nonlinearity of the functional relationship. Preliminary results for the sample of segments under consideration here also confirmed the statistical superiority of the multiplicative hypothesis. For this reason, only multiplicative models are presented below.

4.2.2 Regression Models Including the Entire Set of Variables

The entire set of roadway/roadside and environmental variables was initially tested for inclusion in the regression models. The addition of regressors to the equations was carried out according to a "decision tree" technique, which allowed the systematic exploration of the different combinations of independent variables and the effect of their order of inclusion on the statistical explanation of the model. In this procedure, a branch of the tree is pruned whenever the addition of the corresponding variable is not significant at the desired probability level--usually 5%. Due to the logarithmic structure of the model, segments with no accidents during the period of analysis cannot be considered for analysis. Rather

than eliminate these segments from the sample, it was decided to add one accident to every segment, thereby increasing the mean number of accidents/year by 1/6.

The variables that were found to be significantly related to accident occurrence were the length of the segment (for models of the number of accidents), ADT, and the light condition. Moreover, the relative sizes of the coefficients associated with the corresponding dummy variables were the expected ones (i.e., higher accident frequencies for higher ADT and nighttime). All the remaining variables, including all roadside characteristics, did not add significantly to the statistical explanation of the models, and for some of them the relative sizes of the regression coefficients were not as expected.

An analysis of the complete set of independent variables provides an estimate of the proportion of the total variation explained when all the variables were considered. This yielded $R^2 = 0.78$ for Total Number of Accidents, $R^2 = 0.73$ for Number of Fatal and Injury Accidents, $R^2 = 0.67$ for Total Accident Frequency, and $R^2 = 0.63$ for Fatal and Injury Accident Frequency. It should be noted that the higher values of R^2 found for Number of Accidents reflect the additional correlation between this indicator and the length of the segment.

The equation for Total Accident Frequency including only the nonpolicy variables, which are also the strongest predictors, is as follows:

$$F_T = 0.25(0.23)^{T1}(0.80)^{T2}(1.19)^{T3}(2.00)^{T4}(2.34)^{T5}(0.67)^{D}(1.48)^{N}$$

$R^2 = 0.56$; number of segments = 53.

where F_T is the total total accident frequency (accidents/mile/year);

T_i, i=1,...5, is the percent of length with the following ADT: 1 = $\leq$ 1,000; 2 = 1,000-2,000; 3 = 2,000-3,000; 4 = 3,000-4,000; 5 = $\geq$ 4,000; D is the percent of accidents in daytime; N is the percent of accidents in nightime.

Both of the groups of fractional dummies representing ADT and light condition are statistically significant, as shown in Table 4.4. The structure of the equation indicates that the accident frequency can be interpreted as the product of the geometric mean (0.25) times a coefficient raised to a power representing the fraction of the segment with that characteristic. For example, the estimated accident frequency for a uniform segment with 2,000 < ADT $\leq$ 3000 during the day would be:

$$F_T = (0.25)(1.19)(0.67) = 0.20 \text{ accidents/mile/year}$$

To correct for the adjustment made to be able to use zero accident segments, one needs to subtract 1/((6 years)(segment length)) from this estimate.

The effect of the inclusion of a roadside variable into the model is illustrated by Model 3 in Table 4.4. The set of clear zone width variables was found to contribute only marginally to the explanation of the variance of accident frequency, and the coefficient for 16-21 foot clear zones is low compared to the adjoining coefficients.

$$F_T = 0.25(0.22)^{T1}(0.75)^{T2}(1.18)^{T3}(2.10)^{T4}(2.80)^{T5}(0.68)^{D}(1.45)^{N}$$

$$(1.98)^{Z1}(0.41)^{Z2}(1.58)^{Z3}(1.03)^{Z4}(0.97)^{ZM}$$

$R^2 = 0.61$; number of segments = 53.

where Z_i, i = 1,...4, is the percent of length with the following clear zone widths: 1 = 3-15 feet; 2 = 16-21 feet; 3 = 22-27 feet; 4 = $\geq$ 28 feet;

Z_M is the percent of length with missing data on clear zone width. The other variables have the previously defined meanings.

The sensitivity of the model structure to the choice of the accident indicator used as dependent variable is illustrated by the corresponding equation for Total Number of Accidents:

$$N_T = 1.25(L/5.06)^{1.01}(0.22)^{T1}(0.75)^{T2}(1.18)^{T3}(2.10)^{T4}(2.81)^{T5}(0.68)^{D}(1.45)^{N}$$

$$(1.99)^{Z1}(0.41)^{Z2}(1.57)^{Z3}(1.03)^{Z4}(0.97)^{ZM}$$

$R^2 = 0.66$; number of segments = 53.

where N_T is the total number of accidents (accidents/year); L is the length of segment (miles). The coefficients of the dummy variables representing ADT and light condition do not change significantly from the F_T equation; the coefficient for length is nearly one, indicating the effect of length is linear, unlike the increasing effect of ADT shown in Figure 4.1, which is plotted from the results for Model 4 of Table 4.4.

Models 4 in Tables 4.4 and 4.5 illustrate the combined effect of adding measures of clear zone width and slope to the above two equations. Neither equation exhibits adequate statistical significance, as also suggested by the fluctuations in the coefficients of the ADT and light variables. We believe the lack of significance is mainly related to an insufficient number of segments in the sample rather than a lack of a functional relationship. Accordingly, the following hypothetical equation may be regarded as indicative of the likely statistical association that could be observed with a larger sample size, assuming that the effects of clear zone and slope are independent:

Table 4.4

Detailed Regression Models for Total Accident Frequency
(number of segments - 53)

Variable	Class	Model 1	2	3	4	Variable Means
constant-geometric mean		0.248	0.248	0.248	0.248	-
ADT(1,000s)	0-1	0.219	0.234	0.215	0.229	.115
	1-2	0.765	0.795	0.751	0.744	.375
	2-3	1.242	1.192	1.181	1.183	.242
	3-4	1.863	2.002	2.098	1.777	.112
	> 4	2.662	2.344	2.801	3.083	.156
Light	DAY		0.667	0.681	0.770	.492
	NIGHT		1.480	1.449	1.287	.508
Clear zone width (feet)	3-15			1.982	2.633	.083
	16-21			0.412	0.510	.179
	22-27			1.575	2.040	.205
	≥ 28			1.031	1.833	.411
	missing			0.970	0.054	.122
Slope (x:y)	≥ 3:1				0.970	.359
	4:1				0.657	.230
	≤ 5:1				0.449	.287
	missing				15.180	.124
Statistical measures						
R^2 - model		0.533	0.559	0.607	0.658	
reference model		-	1	2	2	
ΔR^2 over reference		-	0.026	0.048	0.099	
$1-R^2$ (residual)		0.467	0.441	0.393	0.342	
degrees of freedom: Δ; residual		5,48	1,47	4,43	7,40	
partial F		10.95	2.77	1.31	1.65	
probability		< .01	< .10	< .30	< .20	

Note: Although models 2, 3 and 4 have somewhat substantial increases in the proportion of explained variance (ΔR^2), they are not statistically significant as judged by the relatively conservative partial-F test.

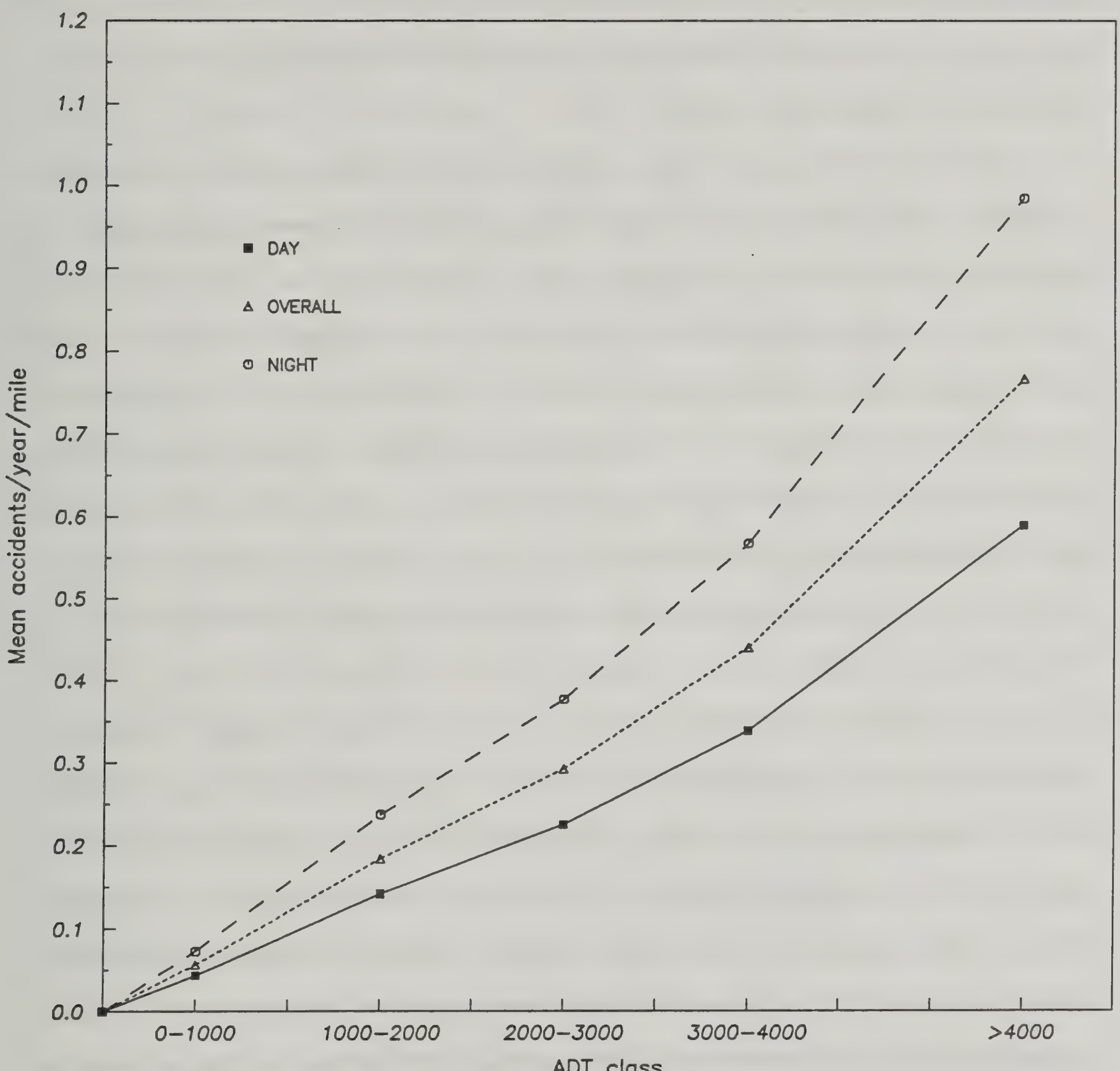

Figure 4.1: Estimated accident frequency vs. ADT class (based on model 4, Table 4.3)

$$F_T = 0.25(0.22)^{T1}(0.74)^{T2}(1.19)^{T3}(1.84)^{T4}(3.05)^{T5}(0.80)^{D}(1.25)^{N}$$
$$(1.11)^{Z1}(1.10)^{Z2}(1.08)^{Z3}(0.91)^{Z4}(1.41)^{S3}(0.91)^{S4}(0.68)^{S5}$$

where Z_i, i = 1,...4, is the percent of length with the following clear zone widths: 1 = 3-15 feet; 2 = 16-21 feet; 3 = 22-27 feet; 4 = $\geq$ 28 feet; and S_j, j = 3,4,5, is the percent of length with the following lateral slopes: 3 = $\geq$ 3:1; 4 = 4:1; 5 = $\leq$ 5:1.

Note that the clear zone and slope coefficients have been adjusted to eliminate the effects of missing data and the very small coefficient for the clear zone width of 16-21 feet. More specifically, for each segment the clear zone width and slope within the part of the segment with missing data are allocated to the different categories in the same proportions as for the remaining part of segment. A regression analysis was performed for this adjusted data. In the resulting regression equation, the coefficient for the clear zone width of 16-21 feet was clearly too small in the same way as in Table 4.4. Therefore, this coefficient was replaced by interpolating the two adjacent coefficients (i.e. those for 3-15 feet and 22-27 feet).

It should be noted that the elimination of the "missing" categories, whose coefficients were markedly different between width and slope, substantially reduces the differences in magnitude of the coefficients of width vs. slope in this hypothetical model. Therefore, the differences in magnitude of the coefficients for clear zone width vs. slope are simply a consequence of the effect of the missing data, and should not be interpreted literally. The statistical significance of this equation is similar to that of Model 4 in Table 4.4.

Based on the adjusted coefficients, we <u>hypothesize</u> that the joint effects of clear zone width and lateral slope <u>might</u> be as shown in Figure

4.2. The figure illustrates the hypothesized effect of a wider clear zone and a flatter slope on accident frequency. Because of the multiplicative form of the model, the hypothesized effect of wider clear zones on accident frequency appears to be greater for steeper slopes ($\geq$ 3:1) than for flatter slopes ($\leq$ 5:1). The estimated percent reduction in accidents in each slope category, however, is the same: 2% reduction in accidents/mile by widening from 3-15 feet to 16-21 feet, 3% reduction by widening from 3-15 feet to 22-27 feet and 23% reduction by widening from 3-15 feet to more than 28 feet.

Finally, and perhaps most importantly, we consider the effect of ADT on accident frequency. The results of Tables 4.4 and 4.5 illustrate convincingly that road segments with higher traffic volumes have substantially greater accident frequencies. The effect of higher traffic increases non- linearly with flow: 3.3 times as many accidents/mile for ADT of 1,000-2,000 as for ADT < 1,000; 5.2 times as many accidents/mile for ADT of 2,000-3,000 as for ADT < 1,000; 7.8 times as many accidents/mile for ADT of 3,000-4,000

as for ADT < 1,000; and 13.5 times as many accidents/mile for ADT > 4,000 as for ADT < 1,000. (Refer to Figure 4.1 for a graphical interpretation of these results including the effect of day and night on accidents/mile.) From these results, it is clear there is no ADT threshold at which accidents/mile begin to increase; rather, the effect is present from very low traffic volumes. The results clearly demonstrate that the effect of wider clear zones (and flatter slopes) on reducing accident frequency will be much more substantial on higher than lower ADT roads.

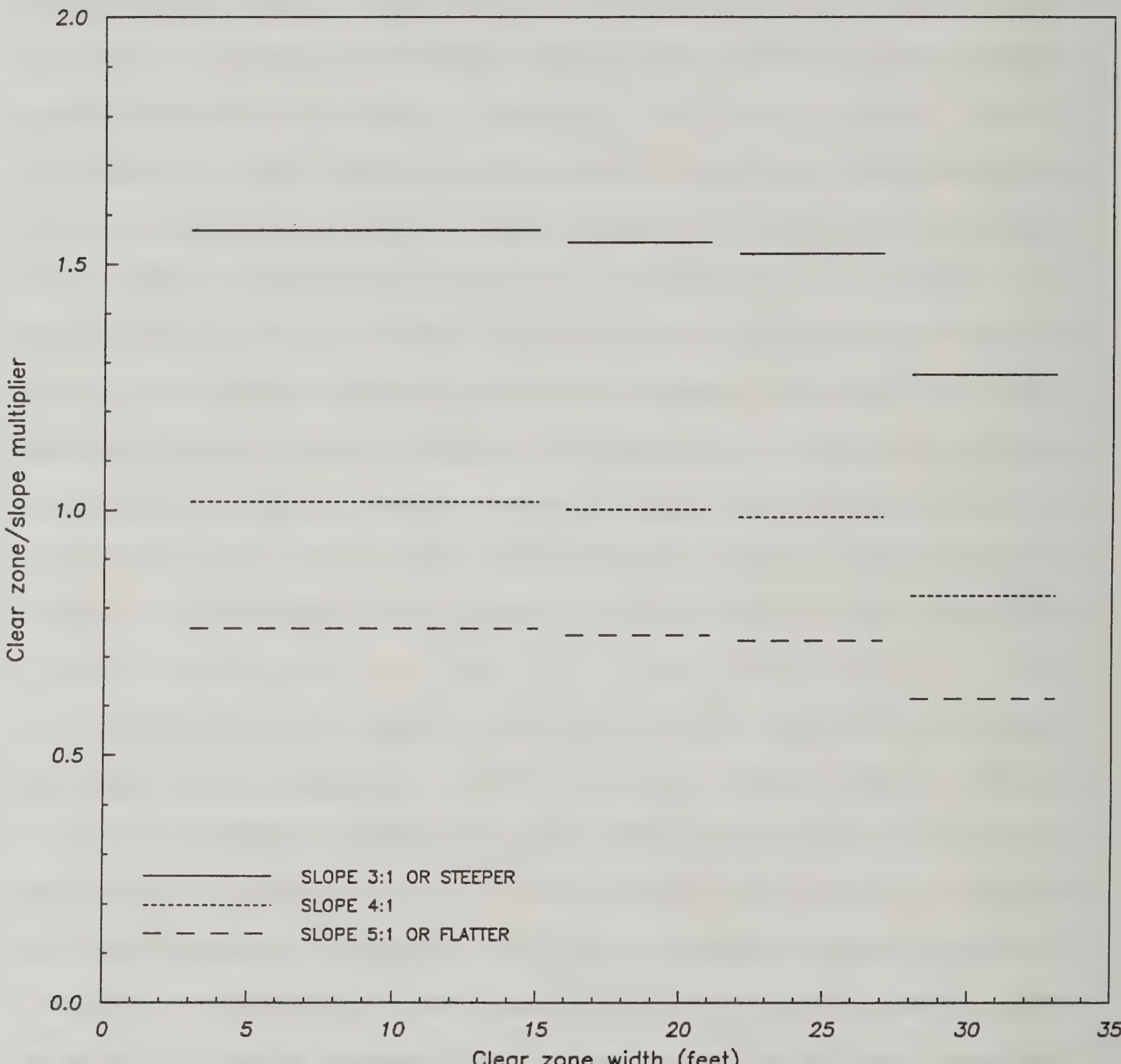

Figure 4.2: Hypothesized clear zone/slope multipliers vs. clear zone width (based on adjusted equation for accident frequency)

Table 4.5

Detailed Regression Models for Total Number of Accidents
(number of segments - 53)

Variable	Class	Model 1	Model 2	Model 3	Model 4	Variable Means
constant-geometric mean		1.254	1.254	1.254	1.254	-
Length (miles)		1.054	1.043	1.011	1.005	5.515
ADT(1,000s)	0-1	0.218	0.233	0.215	0.229	0.115
	1-2	0.766	0.795	0.751	0.743	0.375
	2-3	1.237	1.188	1.181	1.182	0.242
	3-4	1.865	2.002	2.096	1.775	0.112
	> 4	2.686	2.361	2.807	3.083	0.156
Light	DAY		0.668	0.682	0.770	0.492
	NIGHT		1.478	1.449	1.287	0.508
Clear zone width (feet)	3-15			1.986	2.638	0.083
	16-21			0.413	0.511	0.179
	22-27			1.570	2.040	0.205
	≥ 28			1.033	1.837	0.411
	missing			0.966	0.054	0.122
Slope (x:y)	≥ 3:1				0.969	0.359
	4:1				0.656	0.230
	≤ 5:1				0.449	0.287
	missing				15.196	0.124
Statistical measures						
R^2 - model		0.598	0.620	0.662	0.705	
reference model		-	1	2	2	
ΔR^2 over reference		-	0.022	0.042	0.085	
$1-R^2$ (residual)		0.402	0.380	0.338	0.295	
degrees of freedom: Δ; residual		6,47	1,46	4,42	7,39	
partial F		11.65	2.66	1.30	1.61	
probability		< .01	< .20	< .30	< .20	

Note: Although models 2, 3 and 4 have somewhat substantial increases in the proportion of explained variance (ΔR^2), they are not statistically significant as judged by the relatively conservative partial-F test.

4.2.3 Analyses of Other Roadside Characteristics

The findings presented in the above segment, which are the most satisfactory of all the analyses from a statistical viewpoint, are based on roadside data obtained from the cross-section sheets of the construction plans. A substantial amount of the data collection effort was devoted to obtaining information on objects in the right-of-way from the road plan or layout sheets. Three types of data were recorded from the plan views: number of occasional objects in the right-of-way classified by lateral distance intervals from the roadway (e.g. trees, culvert headwalls, signs, etc.); the presence of regular objects classified by lateral distance (e.g. utility poles); and the presence of continuous objects classified by lateral distance (e.g. fences). The presence of these three types of objects within a 400 foot interval was noted every 1,000 or 2,000 feet. The data were coded and analyzed in a similar way to the clear zone and slope data.

In general, the results of the analyses including these roadside data were inconsistent and statistically insignificant. Although the estimated coefficients for each width and object type category were generally decreasing with increasing width, there were many anomalies and the statistical significance was almost nil. Therefore, we believe it is inappropriate to report any detailed numerical results for these analyses.

As with the four models in the above section, an attempt was also made to obtain meaningful results by aggregating these roadside object data. Since this attempt was also unsuccessful, the results are not reported here. The detailed roadside data did prove to be useful in developing a basis for estimating the cost of removing objects from the clear zone. This analysis forms the final chapter of the report.

Chapter 5

Benefits/Cost Analysis of Improving the Roadside Clear Zone

5.1 Introduction

A general approach to evaluating alternative roadside design policies consists of comparing the cost of improving the roadside with the present worth of the savings in lives, injuries and property damage from the corresponding reduction in accidents. This widely-accepted approach implies an ability to determine the several inputs to the procedure as follows: a) the cost of improving an existing roadside to each alternative design; b) the reduction in the number of accidents by type for each proposed design; c) the monetary savings associated with these avoided accidents; d) the life and rate of return of each proposed design. Given these inputs, the benefit-cost ratio or difference, whichever one prefers, may be readily calculated, and the designs ranked in order of their cost-effectiveness.

Assembling these inputs is a formidable task, an observation which explains why most geometric designs are based on standards related to physical laws of motion and human factors research, rather than detailed benefit-cost analyses of individual road segments. In this research project, our principal effort was directed towards extending methods for estimating the difference in accidents associated with alternative designs, as well as analyzing the underlying causes of single-vehicle, run-off-road accidents. A secondary objective was to develop a simple cost model of roadside improvement. In so doing, we have assumed that items (c) and (d) would be available from IDOT policies or other studies.

As has been described in detail in Chapter 4, as well as Chapters 2 and 3, our attempts to develop a technique for estimating accident frequencies has been only partially successful. In particular, the method for estimating the effects of alternative roadside characteristics on the accident frequency is not statistically reliable. Put another way, if we stated these estimates with confidence limits, their range would be so broad as to be rather meaningless.

One principal reason for the unsatisfactory nature of these results is the relatively small sample size that we were able to collect. Other things being equal, a larger sample will increase the statistical significance of the results, although not necessarily the goodness-of-fit of the model to the data. Another reason concerns the reliability of the data actually available, with regard to both accident and roadside characteristics. Nevertheless, we believe our analyses have succeeded in improving the underlying understanding of the relation of roadside clear zone characteristics to the frequency and severity of accidents.

In attempting to develop a simple cost model of roadside design, we also encountered some difficulties. With regard to the question of the clearing the roadside of hazards, it was not possible from available construction plans to characterize obstacles sufficiently precisely to estimate the cost of their removal. This problem was particularly troublesome for the removal of trees in the roadside since no data on the size of trees were available. The cost of relocation of culvert headwalls was also difficult to estimate because the specific characteristics of each culvert relocation are different.

In view of these uncertainties, as well as the question of whether additional right-of-way is required in the typical clear zone widening, we explored an approach in which the unit cost of clearing a hazard is a variable in the analysis, rather than an assumption. Appendix 2 shows unit costs for removal of fixed objects and costs per mile for typical 3R projects. These costs are used in interpreting Figures 5.1 and 5.2. We believe this approach, which is described in Section 5.2, permits us to exploit the data collected during this project to their maximum.

The improvement of the roadside through flattening of embankment and drainage ditch slopes is not a design option under IDOT's 3R program unless the roadway is to be widened. It was necessary to obtain data on these side slopes, however, to analyze the effects of the various roadside hazards, including steep slopes, on accident frequency. For this reason, we have also examined the relation of accident savings to the costs of flattening roadside slopes and associated improvements such as culvert headwall removal and culvert extensions. These findings are reported in Section 5.3.

5.2 Clearing the Roadside of Obstacles

In this section, the focus of the analysis is on the relation of the costs of accidents resulting from vehicles striking obstacles in the roadside to the prevalence of these obstacles. Because it was not possible to obtain a statistically significant estimate of the effect of such obstacles on accident frequency, or to determine the cost of removing the obstacles themselves for the sample of highway segments, it was decided to examine the data in a more exploratory manner. From the data collection activities, an estimate of the number of occasional objects/mile in the roadside of each segment was made for two roadside widths: 0-18 feet, and 0-30 feet.

Occasional objects consist of trees, signs, culvert headwalls, etc. Not included are continuous and uniformly spaced objects such as fences and utility poles. Accident records for 1980-1985 were used to compute the mean annual cost of accidents in which the vehicle struck an occasional object in the roadside. The mean accident cost of $9,210 was multiplied by the annual number of fixed object collisions per mile to determine the annual accident cost/mile for each segment in the sample. The present worth of these costs over a 20 year design life was computed by multiplying by 9.82, the 20 year present worth factor for a rate of return of 8%.

The present worth of the cost of fixed object collisions/mile versus the number of occasional objects/mile for each of the 69 segments for which occasional objects data were available are shown in Figures 5.1 and 5.2 for 18 and 30 foot clear zones respectively. Three symbols are used to indicate the ADT range of the segment; the large symbols indicate the mean values for each ADT range. The four solid rays drawn from the origin correspond to various unit costs of obstacle removal. For example, the ray with the flattest slope is $200/object; thus the point corresponding to an accident cost of $5,000 and 25 occasional objects lies on this ray.

Also shown with dashed rays are the unit costs of removing various objects such as trees and culvert headwalls, listed in Appendix 2A. If the mean number of objects/mile in the roadside in the four improvement projects listed in Appendix 2B was 20, as was observed in our sample, then the mean removal cost per object is about $1500. This ray is also shown.

It is suggested these figures be interpreted in the following way. Suppose the mean unit cost of removing occasional objects is $1500. Then

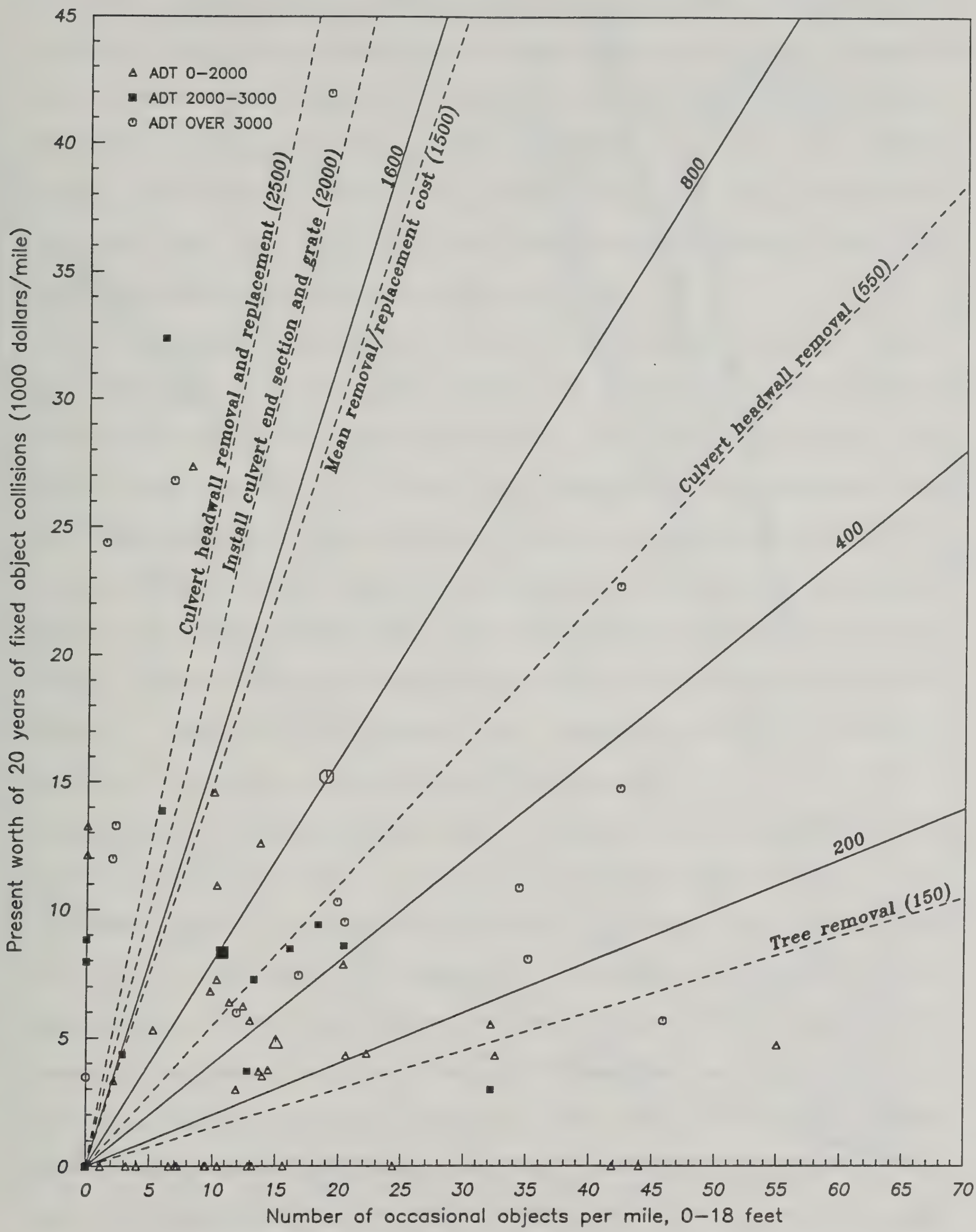

Figure 5.1: Present worth of fixed object collisions vs. number of occasional objects within 18 feet of the roadway

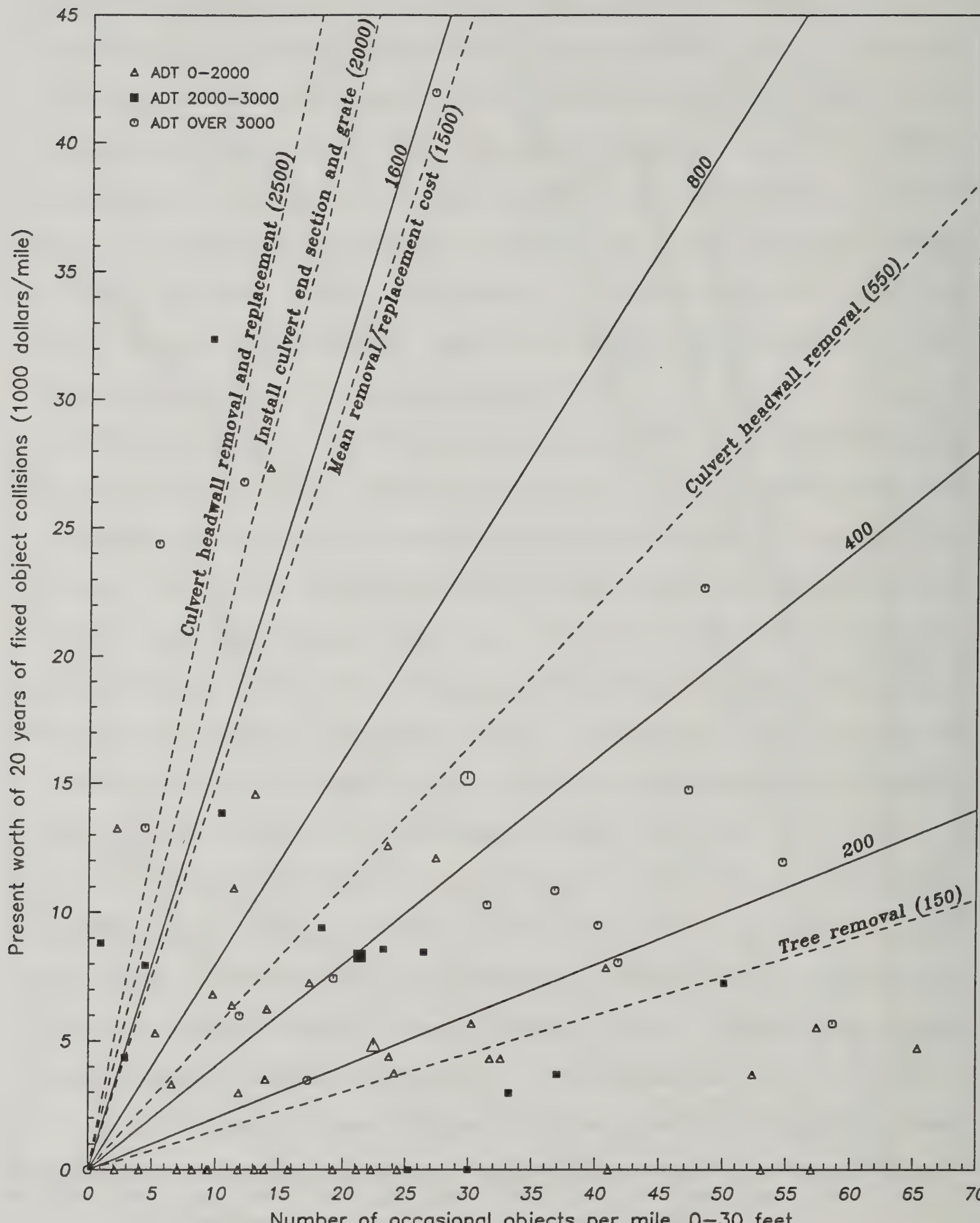

Figure 5.2: Present worth of fixed object collisions vs. number of occasional objects within 30 feet of the roadway

for points representing segments which lie to the right of the $1500 unit cost ray, the accident costs/mile are <u>less</u> than the cost/mile of removing the objects. Even if removal of the objects led to the elimination of <u>all</u> accidents involving collisions with occasional objects, an unlikely result, then for these points the benefit-cost ratio would still be less than one. Note that several of these segments had no reported fixed object collisions during the six year period, 1980-1985.

For segments to the left of the $1500 ray, a benefit-cost ratio greater than one <u>could</u> result if object removal did indeed lead to elimination of some of the accidents. For some segments, such as those lying to the left of the $2500 unit cost ray, removal seems warranted on a benefit-cost ratio basis. It should be noted, however, that these segments are the ones with very few or even no obstacles within 18 feet of the roadway, so that they may be regarded as among least hazardous segments; note that Figure 5.2 reveals, however, that all segments have fixed objects within 30 feet of the roadway. Some of these segments have experienced several accidents as indicated by the present worth of the accident costs.

Figure 5.2 shows the present worth of the cost of collisions with fixed objects versus the number of occasional objects within 30 feet of the roadway. Generally, the points in Figure 5.1 move to the right in Figure 5.2; the accident costs are unchanged. Therefore, in Figure 5.2, more segments lie below a given unit cost ray, meaning a lower unit cost of removal is necessary to justify clearing the roadside to 30 feet.

In examining Figures 5.1 and 5.2, one important question concerns whether more segments with higher ADTs lie to the left of a given ray (e.g. $800) than segments with lower ADTs. If this were true, then the graph

would provide one justification for an ADT-specific clear zone policy. An examination of the position of the segments of each ADT class indicates some tendency for higher ADT segments to lie in the upper left portion of the figure. A count of the number of segments in each of the five wedges defined by the solid rays in Figure 5.1 indicates the higher ADT points generally lie more to the upper left and the lower ADT points more to the lower right. The mean values shown by larger symbols also show some tendency towards a relation to ADT. The distribution of points in Figure 5.2 is somewhat more concentrated toward the lower right, as would be expected by the shift of points toward the right.

Figures 5.1 and 5.2 also suggest the relative merits of removing different types of objects from the roadside. Trees cost much less to remove than culvert headwalls, but are probably equally hazardous. If so, tree removal may be much more cost-effective than any other type of obstacle removal, since nearly all segments with one or more accidents/mile lie above the $150 tree removal ray.

This issue raises an interesting question about the way in which 3R programs are implemented. Generally, a design is prepared for each highway segment <u>selected</u> for improvement; the design may include clearing the roadside of all occasional objects within a specified width. An alternative approach would be to clear all objects of a certain type within a specified width from <u>all</u> highways. The latter approach would result in <u>all roadsides</u> being clear of <u>selected objects</u>, rather than <u>selected roadsides</u> being clear of <u>all objects</u>. Since the risk of a fixed object collision is proportional to the number and location of objects, the latter approach may be more cost-effective.

The costs of removing objects in Appendix 2 are based on construction bids by general contractors. Removal of trees is an activity that is probably performed more efficiently by firms specializing in this business than by general contractors. If the removal costs are quite low, there may be numerous trees in the roadside which are cost-effective candidates for removal. Likewise, utility companies could be urged to relocate their poles to a greater distance from the roadway during routine line rehabilitation programs.

5.3 Flattening and Clearing the Roadside

Flattening the roadside slopes of drainage ditches and embankments is presently not an option in IDOT's 3R program unless the roadway is widened. Roadside improvements to flatten 2:1 foreslopes of drainage ditches and embankments to the 6:1 standard presently used in new construction requires a reconstruction of the roadside. It is clear from the analyses reported in Chapter 4 that steep roadside slopes are associated with higher accident frequencies. For this reason, an analysis of the cost-effectiveness of flattening roadside slopes as well as removing obstacles was undertaken.

A more extensive analysis was performed than is reported here. This analysis estimated the earthwork cost of reshaping and flattening the drainage ditches. A simple cost model was developed which was based on the foreslope, backslope and depth of the drainage ditch. Based on this model, construction cost estimates range from about $33,000 to $70,000/mile. A typical improvement is to flatten a 2:1 foreslope to a 6:1 slope; the estimated earthwork cost for this example is about $70,000/mile.

The following estimates of flattening slopes were calculated:

2:1 to 4:1 - $57,822/mile

2:1 to 6:1 - \$70,212/mile

3:1 to 4:1 - \$39,236/mile

3:1 to 6:1 - \$51,627/mile

4:1 to 6:1 - \$33,041/mile

In addition to the earthwork cost, it is essential to consider the cost of removing roadside objects such as culvert headwalls and trees, and the extension of culverts and replacement of headwalls. In this analysis, these objects were assumed to have a mean removal or replacement cost of \$1500/object.

The total improvement cost/mile was computed as the sum of the earthwork cost and object removal cost for the following combinations:

6:1 slope and 30 foot clear zone

4:1 slope and 18 foot clear zone

By extrapolating the slope and clear zone width data on highway segments with partially missing roadside data, it was possible to compute these costs for 44 segments in the sample.

Corresponding to the improvement cost/mile, an estimate of the savings/mile from avoided accidents is required. For this purpose, the "hypothetical" model on page 52 was selected. This model represents our best estimate of a model with statistically significant coefficients for clear zone width and slope. We emphasize, however, that this model is not statistically significant for our data.

The model was applied in the following way. First, the total number of accidents per mile with the current roadside design, F_c, was estimated; then the total number of accidents/mile for the improved design was estimated: $F_{4:1/18}$ for 4:1 slope and 18 foot clear zone, and $F_{6:1/30}$ for 6:1 slope and

30 foot clear zone. Using these estimates, the proportion by which accidents can be expected to be reduced may be computed as follows:

$$P_{4:1/18} = \left[\frac{F_c - F_{4:1/18}}{F_c} \right]$$

$$P_{6:1/30} = \left[\frac{F_c - F_{6:1/30}}{F_c} \right]$$

These proportions were then applied to the observed annual number of accidents per mile for each segment to estimate the expected reduction in the annual accidents per mile. This estimated reduction was evaluated at $9,210/accident; the present worth over 20 years at 8% rate of return of this reduction was computed for each of the 44 segments.

Figures 5.3 and 5.4 show the present worth of the estimated accident savings versus the estimated improvement cost for each segment classified by ADT. The rays show various benefit/cost ratios. In the case of Figure 5.3 for 4:1 slope and 18 foot clear zone, no segment has a benefit-cost ratio exceeding 0.4. For Figure 5.4 for 6:1 slope and 30 foot clear zone, three segments exceed a benefit-cost ratio of 0.4, but none exceeds 0.7. Thus, no slope/clear zone width improvements to the segments in this sample are warranted by savings in single vehicle run-off-road accidents evaluated at the parameters specified above. It may be noted in Figure 5.4 that segments with ADTs greater than 3,000 generally have higher B/C ratios. This is not surprising since ADT is the most statistically significant variable in the accident estimation equation.

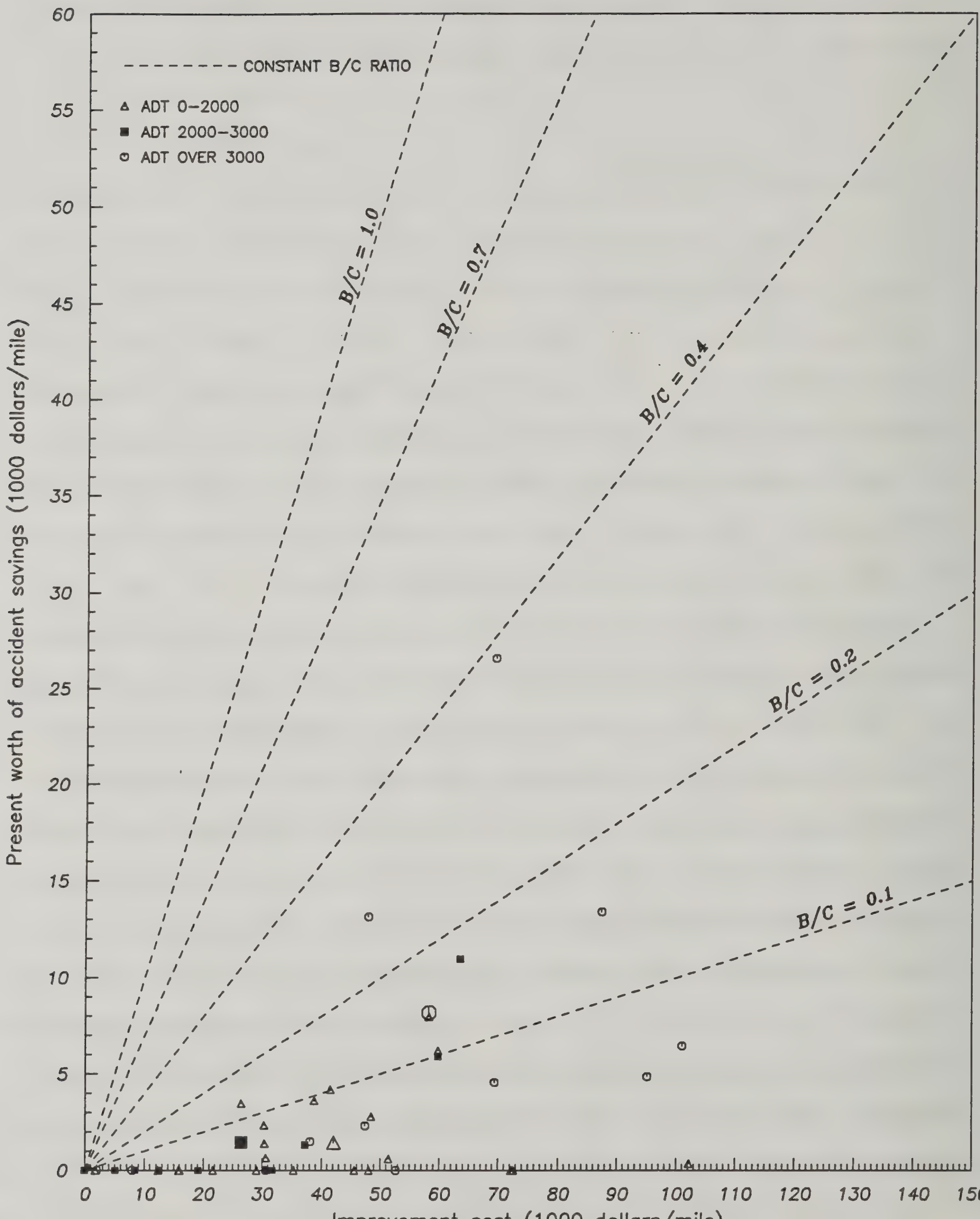

Figure 5.3 : Present worth of accident savings vs. cost of improving the roadside to 4:1 slope and 18 foot clear zone

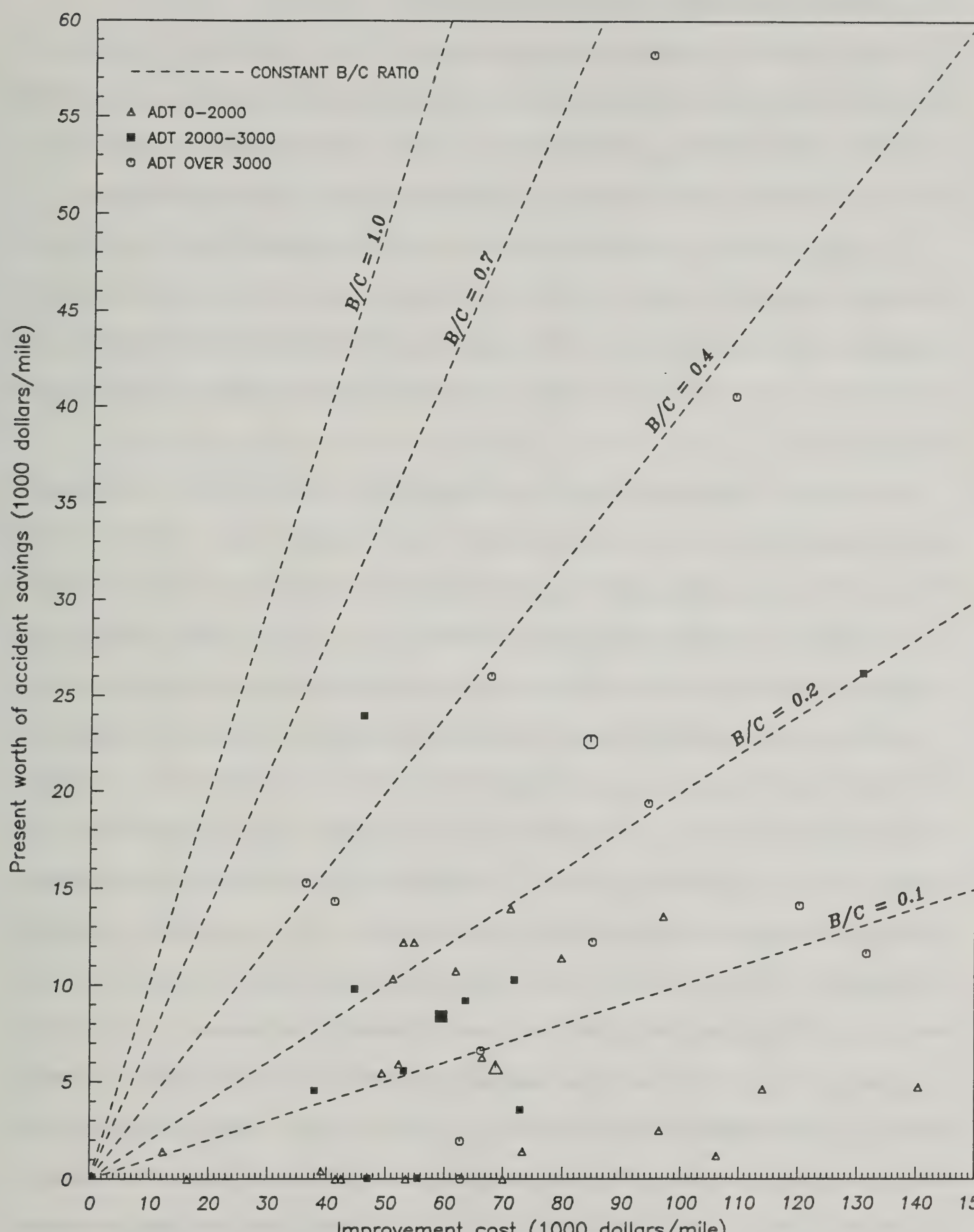

Figure 5.4 : Present worth of accident savings vs. cost of improving the roadside to 6:1 slope and 30 foot clear zone

5.4 General Conclusions and Recommendations

The accident analyses in Chapters 2, 3 and 4 and the benefit-cost analysis in this chapter contribute to our general understanding of roadside accidents and hazards. Unfortunately, they do not provide a basis for a precise recommendation concerning clear zone width in IDOT's 3R program.

In this section, some general conclusions stemming from our analyses, research experience and generally increased awareness of the clear zone question are presented. We have organized this discussion according to improvements costs beginning with lower cost items and moving toward higher cost options.

Little evidence was found to indicate that a specific clear zone width would be cost-effective for a roadway in a certain ADT class. It is noted that accident frequency generally declines with increasing clear zone width and increases with increasing ADT. Sufficient data were not available to examine the combined effect of clear zone width and ADT on accident frequency.

The second conclusion from our research experience concerns the presence of slopes steeper than 2:1 and ditches very close to the roadway. A driver leaving the roadway for any reason on a road with steep ditch slopes has essentially no opportunity to make a recovery in the roadside before either overturning or colliding with the ditch back slope. Such roadsides should be subjected to further analysis since this study was unable to draw specific conclusions for these conditions because of insufficient data.

The cost of clearing the roadside of fixed objects (trees, culvert headwalls and entrances) is generally greater than the present worth of the cost of all collisions involving these objects for most highway segments. For those segments whose accident costs are higher, remedial action should

be considered. Generally, these segments have higher ADTs than other segments. In contrast, for all segments examined the cost of flattening the side slopes and removing all fixed objects exceeded the present worth of the savings from the predicted reduction in run-off-road accidents.

5.5 Future Data Collection, Analysis and Research

In this section, we attempt to collect various observations concerning our research activities that may enhance the success of future studies of this type. This discussion is divided into two parts, data collection and preservation, and data analysis and research.

In general, our experience with IDOT's computerized data system was a positive one. Although we experienced some delays and false starts related to our lack of familiarity with IDOT's roadway and accident data, our experience in working with the data was generally rewarding.

With regard to the road inventory data, the main limitation we experienced was that roadside data are not collected. This fact resulted in our undertaking a rather difficult and tedious data collection effort based on construction plans for contracts let before 1980.

If IDOT expects to conduct analyses of this type in the future, then consideration should be given to incorporation of selected roadside data into the inventory. These items should at least include information on the roadside drainage system including foreslopes and backslopes, location of culverts and headwalls, presence of utility poles, fences and signs, and width of the clear zone as defined by poles and fences. While we understand these data cannot be added all at once, they should be added when roads are reconstructed or rehabilitated, and they should be collected sooner for high accident frequency segments.

Our general experience with IDOT's accident reporting and data management system was also highly positive. One practice was observed, however, which we believe should be modified: computer tapes for accident records older than five years are scratched.

We understand that all computer data files cannot be preserved indefinitely. Given the substantial increase in tape densities that has occurred in recent years, however, older tapes can now be rewritten at much higher densities, thereby preserving these valuable records for future analyses without increasing the number of tapes. In fact, if data had been available for ten years, rather than six, we might have developed a different statistical design that would have provided for a comparison of accident frequencies before and after a 3R project. With fewer years of accident data available, we could not consider this approach.

If analyses of this type are undertaken in the future, as we would recommend, it will be necessary to compile data on a much larger sample of segments in order to improve the statistical significance of the results. A minimum of 200 segments is suggested.

Finally, we provide several observations about this general type of analysis. Our first recommendation is that a broader scope of inquiry should be defined. Indeed, we had an ongoing problem in reminding ourselves that this project was restricted to determining the desirable width of the clear zone and not to other roadside features such as side slope and shoulder width. The real value of performing a benefit-cost analysis of design guidelines is to be able to examine a range of alternative designs and the trade-offs among them. Such trade-offs or ranking of priorities are simply not possible if the scope is extremely narrow.

Our statistical approach also requires that the contribution of various roadside characteristics to accident frequency be considered; once this analysis is completed in a more consistent and statistically reliable manner, the opportunity to make these trade-offs will be available and should be utilized to the maximum. Likewise, the cost of roadside improvement programs are not strictly the sum of the unit costs, but are often jointly determined.

Our general point of view is that the roadside, as well as the roadway, of each segment should be configured for the range of traffic and other conditions expected in the future so as to yield the largest benefit-cost ratio. This result can only be accomplished if a relatively broad range of design alternatives is considered.

Finally, we would emphasize that the data and analysis developed for such a system should be employed not only in roadside design, but also in preliminary engineering studies on which project evaluation and selection are based. Although we are not familiar with the details of IDOT's project selection system, we believe that a fully developed accident frequency model based on the prototype developed in this project would be a valuable asset to the evaluation process in future years.

References

J. C. Glennon and C. J. Wilton (1974) Effectiveness of Roadside Safety Improvements, Volume I, Federal Highway Administration, Washington, DC.

J. L. Graham and D. W. Harwood (1982) Effectiveness of Clear Recovery Zones, National Cooperative Highway Research Report 247, Transportation Research Board, Washington, DC.

C. Meneguzzer (1986) "Safety Effectiveness of Roadside Design of Highways: A Literature Review," Interim Report to Illinois Department of Transportation, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, IL.

APPENDIX 1

Safety Effectiveness Of Roadside Design Of Highways: A Literature Review*

1. Introduction

The purpose of this appendix is to review and to summarize some of the most significant research contributions carried out to date on the roadside safety problem. In particular, it focuses on the evaluation of the cost and safety effectiveness of highway clear recovery zones. This appendix was prepared as the first stage of a broader research project on the effectiveness of roadside policies for two-lane rural highways in Illinois; therefore, it is not to be considered as an exhaustive analysis of the existing literature dealing with roadside safety, but rather as a summary of some of the most important work previously done on this subject.

2. Definitions and Problem Statement

Data from the Fatal Accident Reporting System for the first six months of 1984 (Cerrelli, 1984) showed that 42% of the fatal accidents involved a single vehicle and they contributed to 41% of the traffic fatalities in that same time period. During the entire year of 1983, the National Safety Council indicated that 35% of fatalities due to motor vehicle crashes occurred when single vehicles struck fixed objects or were involved in noncollision crashes.

Several previous studies consistently indicate the importance of single-vehicle accidents, largely due to the fact that the probability of

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*This appendix was prepared by Claudio Meneguzzer.

injury and the relative severity of this type of accidents are significantly higher than for the other categories of accidents.

Single-vehicle accidents may be classified into different types:

1. vehicle ran off the road and struck fixed object;
2. vehicle ran off the road and overturned;
3. vehicle overturned on road;
4. vehicle collided on road with fixed object.

Since this report is concerned only with accidents involving the roadside, only the first two categories are of interest here.

In order to reduce the consequences from off-road accidents, different countermeasures are available. A general roadside improvement strategy, as outlined in the report Highway Design and Operational Practices Related to Highway Safety (AASHO, 1967), can be summarized as follows:

1. remove roadside obstacles;
2. move obstacles that cannot be removed, including moving them to a protected location or moving them laterally;
3. reduce the impact severity of obstacles that cannot be moved, including weakening obstacles so that they break away without damaging the vehicle extensively;
4. protect the driver from obstacles that cannot be otherwise improved, using attenuation or deflection devices;
5. reshape and stabilize roadside ground forms to improve vehicle stability under emergency conditions, including flattening side slopes.

In a given roadside improvement program, one or more of the above countermeasures can be implemented in combination, depending essentially on the

situation existing before the improvement, on the funds available and on the "degree of safety" which is desired to result from the new roadside design.

A clear zone, as defined in the NCHRP report 247 (Graham and Harwood, 1982) is "a relatively flat roadside area free of unprotected fixed objects and other nontraversable hazards, intended to provide an opportunity for vehicles that leave the roadway to come to a safe stop or to return to the roadway." It is worth adding to this definition that this roadside area is considered to start at the edge of the traveled way, so that the shoulder, whenever present in the cross-section is included in the clear zone.

Since the late 1960s a 30 foot wide clear zone has come into use for new construction and major reconstruction projects. The adoption of this design concept was essentially based on research carried out at the General Motors Proving Ground; findings of this research indicated that up to 80% of vehicles leaving the roadway could recover within 33 feet of the pavement edge if no obstacle was encountered preventing the recovery. The study also concluded that "for safe roadside design the slopes must be as flat as possible, not steeper than 6:1 and preferably flatter". Another recommendation was to avoid installation of guardrail wherever possible, since guardrail itself constitutes a roadside hazard.

The 30 foot clear zone concept was incorporated in the previously mentioned AASHO report (published in 1967 and commonly known as the "Yellow Book"), and became part of the Federal Highway Administration guidelines for new freeway construction and for some new construction and reconstruction projects on other types of highways. However, many existing highways have clear zones with 4:1 roadside slopes or have no clear zone at all.

The AASHTO (1977) Guide for Selecting, Locating and Designing Traffic Barriers introduced some modifications intended to make the roadside design policies more flexible and more sensitive to possible variations in traffic conditions and geometric characteristics. The suggested width of clear zone is variable depending on the vehicle operating speed and on the embankment slope, with different values for cut and fill cross-sections. The Guide further suggests that a barrier be used in cases where the required width is not available and the obstacles cannot be removed. The Guide also provides for wider clear zones on the outside of curves and for narrower clear zones for highways with traffic volumes below 6,000 vehicles/day.

The Supplement to a Guide for Selecting, Designing and Locating Traffic Barriers (TTI,1980, 1981), prepared by the Texas Transportation Institute for FHWA, contains a set of charts developed by the Minnesota Department of Transportation that provide a quick method of determining clear zone width based on operating speed, degree of curve, roadside slope (cut and fill) and traffic volume.

Since our study will focus on roadside policies for Illinois highways, it is worth considering in particular the clear zones requirements stated by the Illinois Department of Transportation. The IDOT Memorandum (1983) Policies for the Rehabilitation of Highways and Bridges on Marked Routes of the State Highway System in Illinois recommends for speeds of 45 mph or greater that the clear zone width be 18 feet for ADT above 3,000 and at least 12 feet (with 18 feet still indicated as "desirable") for ADT below 3,000; for speeds less than 45 mph and for all ADTs the shoulder width is assumed to be sufficient as a clear recovery zone.

The ultimate purpose of all research in the area of roadside safety is to provide a quantitative basis for cost-effectiveness evaluation of alternative roadside design policies. That is, there is a need to know if certain proposed roadside improvement programs are economically justified; this requires a comparison between the cost of implementing the new design standards and the benefit derived from the reduction of the number and severity of run-off-road accidents. The need for this type of analysis obviously arises from the circumstance that funds available to highway agencies are usually limited, and therefore different improvement programs are to be ranked according to their benefit-cost ratio. It may be possible that alternative programs aimed at improving geometric characteristics of the roadway (such as, for example, vertical and horizontal alignment) result in a higher benefit-cost ratio than that accruing from providing or widening a clear roadside. The fact that the highway elements and characteristics are interrelated further implies that, at least in principle, the design of a cost-safety effective highway would require the simultaneous consideration of all the various design elements. This is obviously a very difficult task and therefore it seems reasonable, for practical purposes, to perform a separate cost-effectiveness analysis for each relevant design element and then to rank the improvement programs so as to make the most effective use of the available resources.

Two different approaches can be adopted for determining the relationship between accident frequency and severity and traffic and geometric characteristics (and in particular roadside design policies) of highways. A first way of dealing with the problem consists of making an inventory of traffic and geometric design features for a selected number of highway

segments and determining accident rates for these segments. Based on these sets of data, a functional form expressing the relationship between accident rates and traffic and geometric characteristics can be determined and a model can be estimated and used to forecast the effects of a given improvement program. As an alternative, or as a complement, a before/after analysis can be performed on a limited number of sites, when suitable conditions exist.

A second approach can be adopted in cases where accident data are not available: a model can be selected from the existing literature and applied to the situation under consideration, if basic similarities (type of highway, ADT range, etc.) exist with the situation under which the original model was developed and calibrated. As an alternative, or as a complement, a computer simulation can be used.

The remainder of this paper is devoted to a review of several studies on roadside safety, with particular emphasis on those dealing with the relationship between clear zone characteristics and run-off-road accident rates.

3. Literature Review

One of the earliest and most important contributions in the area of roadside safety is due to K. Stonex (1960), who carried out his work at the General Motors Proving Ground in Milford, Michigan. The importance of clear roadside areas in improving vehicle safety was recognized based on data indicating that 72% of the accidents occurring at the Proving Ground in the period 1953-1958 involved vehicles leaving the roadway. In another study by Stonex, the distribution of lateral distances traveled by encroaching vehicles was studied. Out of 211 run-off-road accidents at the GM Proving

Ground, it was determined that 80% of the vehicles did not travel more than 30 feet from the pavement, 90% did not travel more than 50 feet and no vehicle traveled more than 102 feet. As said earlier, the adoption of the 30 foot clear zone concept and the idea that roadside slopes should be as flat as possible, are mainly attributable to the pioneering work of Stonex.

A major contribution to the understanding of the nature and causes of roadside encroachments is the study by J. W. Hutchinson and T. W. Kennedy (1965). The ultimate purpose of this study was to determine desirable widths and cross sections for the medians of divided highways; it included the investigation of the frequency, nature and possible causes of vehicle encroachments upon medians. Based on empirical data, a number of relationship and distributions were determined; among these were relationships between traffic volume and frequency of roadside encroachments, average encroachment angle, percentage of encroaching vehicles that crossed the median, average maximum lateral distance traveled by encroaching vehicles, and the distributions of encroachment angles and lateral displacements of encroaching vehicles.

The most significant conclusions and recommendations of the study were the following: (1) flatter median cross slopes are desirable as a means of decreasing the maximum lateral extent of movement of encroaching vehicles; (2) existing median appurtenances and obstacles (such as culvert headwalls, drainage inlet structures, etc.) should be reduced to the smallest practical number and designed to present the least possible hazard to the passage of vehicles entering the median at speeds comparable to normal highway operating speeds; (3) a 30 foot wide obstacle-free median with mild cross slopes (24:1 for a 30 foot wide median and steeper allowable slopes for greater

median widths) appears to be the desirable minimum standard for the relatively safe stopping or control of vehicles encroaching on rural highway medians. The installation of suitable median barriers on the basis of traffic volume warrants should be considered when these provisions cannot be made; (4) curves, the approaches to curves, and the areas immediately downstream from grade separation structures should be avoided as locations for large roadside signs. It is important to point out that this study contributed to the adoption of the 30 foot clear zone concept because it documented that very few vehicles encroached beyond 30 foot from the edge of the roadway.

A study on the effectiveness of clear zones was conducted in the mid-1970's by the Missouri Highway and Transportation Department (undated). The objective of this study was to compare the accident experience of highway segments constructed under two different roadside design policies, that is with or without 20 foot "safety zones". The segments with 20 foot "safety zones" had a 20 foot wide obstacle-free roadside area beyond the shoulder and generally 6:1 embankment slopes, while the segments without "safety zones" had no roadside clearance and generally 4:1 or steeper embankment slopes. It is worth noting that, if a 10 foot shoulder is present, the 20 foot "safety zone" is equivalent to a 30 foot clear zone since the latter is measured from the edge of the traveled way.

Four different types of highways were considered in this study. The analysis of accident rates was carried out with respect to four accident types (multiple-vehicle collisions, roadside obstacle collisions, overturning accidents and total accidents) and three severity levels (fatal, injury and property damage only.

The results indicated no statistically significant difference in the overall accident rate or severity between segments with and without clear zones for any of the highway types considered; all the accident rates are expressed in accidents per million vehicle-miles. Considering the different accident types, a decrease in roadside obstacle collisions was observed for the clear zone-segments, while the multiple-vehicle collisions showed a corresponding increase.

The conclusion of the study was that the adoption of the 20 foot "safety zone" was not significantly effective in terms of reduction of the number and severity of accidents. Moreover, the fact that the multiple-vehicle collisions were found to be increased, indicated that the number of persons and vehicles involved in accidents could have increased. Since much of the increase in multiple-vehicle accidents occurred at intersections at least in segments with lower traffic volumes, a possible explanation proposed by the authors was the drivers confusion near the intersections, generated by the expanse of cleared right-of-way.

Another study of roadside design policies performed by V. E. Dotson (1974) focussed on the evaluation of the safety performance of highway sections built under standards complying with the 30 foot clear zone concept. Study segments were selected on four Interstate routes (I-57, I-70, I-72, I-74). Based on cross-section and safety characteristics, three different roadside policies were identified: 6:1, 4:1 Safety, 4:1 Other.

Segments classified as 6:1 generally satisfied all AASHO requirements (essentially 6:1 embankment slopes and 30 foot clear roadside area); on 4:1 Safety segments the 30 foot clearance was generally provided, and safety standards were adopted in the design of elements (for example, grated median

inlets); the category labeled 4:1 Other included older segments constructed with 4:1 embankment slopes that had not been upgraded since the adoption of the safety standards; these segments had generally clear roadsides, but did not conform to the standards in some respects including the treatment of sign supports, culvert headwalls, etc. The fact that each route had particular characteristics did not allow an overall comparison of cross-section and safety features versus accident rates.

Accident data for the period January 1, 1968 to June 30, 1973 was obtained for the segments under study. The types of accident considered were the following: single vehicle run-off-road, single vehicle other, multiple vehicle. These categories were further divided into subcategories based on the type of collision and the involvements occurring in the accident. Using ADT values, the total exposure for each segment was computed in hundred million vehicle miles. A roadway inventory for the study segments was made based on construction and design plans and on a field survey. Moreover, segments subject to change due to safety projects were identified and the general nature of the improvement noted. Accident analysis was performed using three different indicators: accidents, injuries and fatalities. All values were stated in terms of rates per hundred million vehicle miles.

The main conclusions drawn by the author were the following. (1) The proportion of single vehicle run-off-road accidents to total accidents was nearly constant for the four Interstate routes under study. (2) Highway segments built to 6:1 safety standards incorporating elements of the 30 foot clear zone generally showed lower accident, injury, and fatality rates than older segments (both in terms of multiple vehicle accidents and single

vehicle run-off-road accidents), but these differences were found to be not statistically significant. In particular I-70, which consisted almost entirely of 6:1 segments, exhibited a better safety record in both types of accidents than the other routes. However, the author gives no indication about the statistical significance of this result; (3) On segments where the 6:1 roadside design policy was adopted, multiple vehicle accident rates were generally lower, but again no statistically significant difference was found. The author proposes as a possible explanation the better design of interchanges and the greater degree of maneuverability available to avoid accidents on the newer designed segments.

A further part of this research consisted of a before/after study, whose purpose was to evaluate the effectiveness of improvements made to incorporate features of the 30 foot clear zone policy. The accident analysis was performed on two segments which provided 18 months of data after completion of the improvement. The safety improvements consisted of removal of headwalls and replacement with sloped and grated headwalls plus protection of piers and bridge wingwalls with guardrail. In addition, signs with breakaway supports were replaced with clearances greater than 30 feet. The accident analysis for these two locations showed no evident safety improvement after the completion of the projects. However, the author points out that the exposure and the number of accidents for the two segments are too small, so that no statistically significant conclusions can be drawn. A tendency for an increased involvement with guardrail and for less involvements with signs was also observed. Although based on a small number of accidents, this result was interpreted as a support for the policy

of using guardrail only where hitting an obstacle or leaving the roadway would result in a more severe accident than hitting the guardrail.

A study on the relative effectiveness of roadside and roadway improvements was conducted by the Ohio Department of Transportation. This research focussed on the effect of three variables on single-vehicle accident frequency and severity for rural two-lane highways. These variables are roadway width, "shoulder quality" (defined as the presence or absence of a stabilized shoulder) and "roadside quality" (defined as the presence or absence of a 12 to 15 foot clear zone outside of the shoulder).

The most significant result of the analysis was that the reduction in single-vehicle accident rates deriving from the presence of a stabilized shoulder and/or from a wider roadway was greater than that obtained by improving the "roadside quality." These findings clearly indicate the possibility (already stressed in an earlier part of this paper) that improvements of roadway and/or shoulder characteristics may result in larger benefits (or, more generally, in a higher benefit-cost ratio) than those deriving from the provision of roadside clearance.

In many cases, the need may arise of evaluating expected accident rates for roadside design situations where accident data are not available. In such cases, a suitable alternative to the "empirical" approach is the application of a model.

An interesting roadside hazard model was formulated in the NCHRP (1974) report 148 Roadside safety improvement programs on freeways: a cost-effectiveness priority approach. The general goal of this research was to provide a framework for comparing alternative roadside improvement programs and ranking them into a priority scheme. To evaluate the effectiveness of

roadside safety improvements, a probabilistic hazard index model was developed; the predicted difference between the hazard indices before and after improvement was selected as a measure of the effectiveness of the improvement. The basic idea underlying the hazard model under consideration is that, for an impact with a roadside obstacle to occur, three conditions must exist: (1) the vehicle must be within the segment of roadway associated with the roadside obstacle; (2) vehicle encroachment must occur; (3) the lateral displacement of the vehicle must be on a course of impact with the roadside obstacle. Based on this sequence of events, a general expression for the hazard index was proposed. Given a roadway segment of length L associated with a particular roadside obstacle, this expression is:

$$H = V[P(E)][P(C|E)][P(I|C)] \tag{1}$$

where H is the hazard index, which may be defined in various ways (for example, the expected number of fatal plus nonfatal injury accidents per year); V is the vehicle exposure (number of vehicles per year passing through segments L); P(E) is the probability that a vehicle will encroach on the roadside within segment L (encroachments per vehicle). This probability is a function of the length of the segment, L, and other variables such as the geometric design of the roadway; $P(C|E)$ is the probability of a collision, given that an encroachment has occurred (accidents per encroachment). This probability is a function of the angle of encroachment, the vehicle's displacement, the lateral placement of the roadside obstacle, and the size of the obstacle; $P(I|C)$ is the probability of an injury (fatal or nonfatal) accident, given a collision (fatal plus nonfatal injury accidents per total accidents).

It is important to stress that the definition of the hazard index depends on the definition of accident severity (average accident consequence for the particular obstacle) which, in turn, depends on the objective of the roadside safety improvement program; for example, a severity index could be defined as average property damage cost per accident, or average number of fatalities per accident, or average number of fatal and nonfatal injuries per accident, etc.

To make expression (1) suitable for operational applications, an explicit mathematical relationship for the hazard index was given by the author. The variables involved in this relationship are: the encroachment frequency (number of encroachments per mile per year); the severity index (number of fatal and nonfatal injury accidents per total accidents); the dimensions of the obstacle (length and width); the lateral placement of the obstacle; the width of the vehicle; the angle of encroachment; the longitudinal distance from the farthest downstream encroachment point to the encroachment point of reference; and the percentile distribution of lateral displacements of encroaching vehicles. To increase the mathematical tractability of the model, some simplifications were introduced; the simplified hazard model involves basically the same variables as the original one, but can be expressed by a more understandable algebraic form. As regards the information required for the actual application of the model, explicit reference is made to the study by Hutchinson and Kennedy (1965) which, as noted earlier reports empirical data on the relationships that characterize the vehicle encroachment phenomenon (frequency of roadside encroachment as a function of several known parameters, distribution of

encroachment angles, and distribution of lateral and/or longitudinal displacements of encroaching vehicles).

The criterion used to measure the effectiveness of a particular roadside safety improvement program is based on the difference between the hazard indices before and after the improvement:

$$E = H(\text{before}) - H(\text{after}) \tag{2}$$

Considering the particular type of hazard index previously defined, E would be the number of fatal and nonfatal injury accidents reduced per year. A very important point to be emphasized when this type of analysis is performed is that, in most real situations, at a certain site there is more than one obstacle with which a vehicle may come in contact. That is, generally the hazard index of a particular roadside obstacle is not independent of other contiguous roadside obstacles. Since this problem is rather complex, the report does not propose a general approach to deal with it, but suggests certain adjustments to the model that are necessary in the most common multiple-obstacle situation: the simultaneous presence of an embankment side slope and some other type of obstacle (for example, a sign). Some examples of roadside safety improvement situations are given in order to stress the importance of considering the embankment hazard: in many cases, especially for the more severe embankments, the hazard contribution of the embankment can negate any improvement of the obstacle.

The report further contains an outline of the cost-effectiveness approach to be used as a method for obtaining an improvement priority measure. This measure is defined as:

Cost effectiveness

= (annualized cost of improvement alternative)/(hazard reduction achieved)

= cost to reduce one injury (fatal or nonfatal) accident.

The lower the ratio, the more cost-effective is the improvement. The total annualized cost of the improvement alternative is expressed by the following relationship:

$$C_T = C_F - \frac{C_O H_O}{S_O} + \frac{C_I H_I}{S_I} + C_{OM} - C_{IM} \qquad (3)$$

where: C_T = total annualized cost; C_F = annualized first cost; C_O = average annualized maintenance cost per collision with the original obstacle; H_O = independent hazard index for the obstacle; S_O = severity index of the obstacle; C_I = average annualized maintenance cost per collision with the improvement; H_I = independent hazard index for the improvement; S_I = severity index of the improvement; C_{OM} = annualized normal maintenance cost for the obstacle; C_{IM} = annualized normal maintenance cost for the improvement.

It is worth noting that some improvements may have a lower total cost than first cost because of a reduced maintenance requirement (for example, sign removal), while other improvements may have a higher total cost than first cost because of an increased maintenance requirement (for example, installation of guardrail at a bridge abutment, or conversion of rigid signs to breakaway).

Besides the cost-effectiveness criterion, other factors may affect the actual implementation of an improvement program. In many situations, program constraints may be desirable; in particular, a minimum value for the hazard reduction effectiveness and/or a maximum limit on the cost-

effectiveness ratio may be set (the latter is appropriate, for example, when other programs compete for safety funds).

Finally, the report includes some general suggestions on implementation procedures and three appendices containing single-vehicle accident severity data, costs of roadside safety improvements, and an example priority program, respectively. An interesting indication regards the combined use of the probabilistic hazard index model approach and of high accident frequency identification procedures: the cost-effectiveness program identifies potentially hazardous locations, while the high accident frequency procedure identifies locations with demonstrated high degrees of hazard, which may or may not be identified in the cost-effectiveness program. A spot-improvement program is usually appropriate for the latter type of locations.

A study conducted at the Georgia Institute of Technology and reported by P. H. Wright and K. K. Mak (1976) concerns the problem of single-vehicle, off-road, fixed-object accidents. Even though this research focuses on urban highways, it may be of interest here because of the broad set of variables that are considered in developing the accident model.

The study was based on a sample of 45 segments of two-lane streets in Atlanta, each approximately one mile in length. The roadway and traffic characteristics identified for the analysis were: X_1 - ADT; X_2 - Total pavement width; X_3 - Speed limit; X_4 - Number of intersections per mile; X_5 - Number of driveways per mile; X_6 - Horizontal alignment (number of curves > 4^{o}); X_7 - Horizontal alignment (average degree of curve for curves > 4^{o}); X_8 - Vertical alignment (percent roadway with gradient > four percent); X_9 - Vertical curvature (percent per station); X_{10} - Number of discrete objects,

0-5 feet from pavement edge; X_{11} - Continuous objects, 0-10 feet from pavement edge (percent roadway).

In addition to these characteristics, a set of socioeconomic variables was considered as possibly related to the accident rates. These variables were: S_1 - Population density; S_2 - Driving population; S_3 - Percent of Negro population; S_4 - Number of housing units per square mile; S_5 - Annual median income per housing unit; S_6 - Median number of automobiles per housing unit; S_7 - Median number of years of education; S_8 - Percent of employment; S_9 - Percent driving to work.

Two different measures of accident rates were selected and evaluated based on a three-year period of accident data: Y_1 - Single-vehicle, off-road, fixed-object accident rate per mile per year; Y_2 - Single-vehicle, off-road, fixed-object accident rate per million vehicle miles.

Several analyses were performed on the data in order to identify significant accident relationships: correlation and factor analyses on the roadway and traffic variables and on the socioeconomic variables; simple linear regression and stepwise multiple linear regression analyses to establish relationships between the roadway, traffic and socioeconomic characteristics and accident rates; tests for statistical significance on the regression models and on the regression coefficients; residual analysis to identify possible nonlinearity and regularity in the data. Simple linear regression and stepwise multiple linear regression analyses did not reveal any significant relationship between socioeconomic variables and off-road accident rates; only population density was found to be marginally significant, with 9% of the variation in off-road accidents per mile explained by a two-dimensional linear model.

Multiple regression models were further developed to represent the relationships between accident rates and roadway and traffic characteristics. The model for single-vehicle, off-road, fixed object accidents per mile is the following:

$$Y_1 = 0.00021\ X_1 + 0.2\ X_4 + 0.24\ X_6 + 0.41, \qquad R^2 = 0.26 \tag{4}$$

The squared multiple correlation coefficient (R^2 shows that 26% of the variation in off-road accidents per mile is explained by this model. Each of the three variables appearing in this model was also found to be significantly related to Y_1 by simple linear regression. Another multiple linear regression model was Y_2 (single-vehicle, off-road, fixed-object accidents per million vehicle miles):

$$Y_2 = -\ 0.0001\ X_1 + 0.13\ X_6 + 2.14, \qquad R^2 = 0.41 \tag{5}$$

The value of R^2 indicates that this model is statistically superior to the previous one. The authors give as a possible explanation of this result the fact that the number of off-road accidents per mile is mainly a function of the level of exposure. It is worth noting that ADT is negatively related to off-road accidents per MVM, while the coefficient of ADT in equation (4) is positive. This is consistent with the fact that the accident rate per MVM takes into consideration the level of exposure; since generally high-volume roadways have better geometric characteristics and lower operating speed, the probability of off-road accidents is lower on this type of highways. The authors further stress that the relatively low values of R^2 found for both models do not allow its reliable utilization for forecasting purposes since only 26% and 41%, respectively, of the variations in off-road accident rates are explained by the independent variables examined. This is probably due to the fact that other variables not explicitly taken into account in

the models, such as human factors and vehicular characteristics, play an important role in causing off-road accidents. Another important conclusion of this study is that horizontal alignment appears to be the most significant roadway characteristic related to off-road accident occurrence.

A roadside hazard model was developed by Hall and Mulinazzi (1978) in a study of single-vehicle fixed-object accidents, sponsored by the Maryland Department of Transportation in an effort to implement cost-effective solutions to the problem.

The model was formulated as follows:

$$H = K\, f_1(D)\, f_2(S)\, f_3(SI)\, f_4(V)\, f_5(G) \tag{6}$$

where: H = relative hazard of a particular object; K = a normalizing constant; D = distance of the object from the road edge; S = prevailing speed of traffic on the roadway; SI = severity index associated with the type of object; V = volume of traffic; G = geometric conditions.

The implementation of this model requires determination of the values of the factors that express the effect of the various parameters on the hazard index. For each parameter, a series of values and the corresponding values of f_i are given by the authors; in particular, the characteristics considered for the variable "geometric conditions" are roadway grade and curvature and placement of the fixed object (specified as "inside", "tangent", or "outside"). The criteria adopted for the determination of the values of the factors rely mainly on the following considerations: each factor must be based on data that can be easily obtained from field studies and the existing record system; for a given parameter, the factors must recognize in a logical manner the varying level of hazard associated with

that parameter; the quantification must recognize that individual parameters are not necessarily independent nor of equal importance; the resulting hazard index should be proportional to the combined effect of the expected frequency and severity of accidents.

The possible applications of this model include the determination of a priority ranking for roadside improvements, based on the calculation of the relative hazard associated with the various fixed objects, and the relative assessment of different forms of remedial action. The hazard index reduction obtained with the implementation of alternative improvement programs may be combined with economic considerations in a cost-effectiveness analysis. An interesting feature of this model is that it allows the evaluation of the hazard of fixed objects under different roadway designs and operating conditions.

A study on off-road accidents on rural two-lane highways was conducted at the University of Michigan (Cleveland and Kitamura, 1978) to provide the Michigan Department of State Highways and Transportation with guidelines for the formulation of roadside improvement programs.

The data base for this research consisted of statewide accident data for all two-lane rural roads for the period 1971-1974. Analysis of this data revealed that 75% of the off-road accidents on rural two-lane highways was fixed-object collisions, while 25% was represented by turnover accidents. As regards the severity, it was found that approximately one-third of the fixed-object accidents and three-fifths of the turnover accidents involved injuries or fatalities.

Other significant findings of this study were the following: the off-road accident rate decreased with increasing ADT; roadway alignment had

a dominant effect on the severity of these accidents (in particular, a high rate of injury accidents on curves was found); the relative importance of turnover accidents, in comparison with fixed-object accidents, was greater on curves; the severity of accidents was related to the type of object struck, to roadway alignment and to the location of accidents in intersection or non-intersection areas. The study also found considerable variations in the frequency of off-road accidents on the 270 two-mile segments which formed the sample under consideration.

The first stage in the construction of the model was the identification of a group of 19 variables that were expected to be causal or strongly associated with the occurrence of off-road accidents. The above mentioned sample (which represented about 10% of total rural MDSHT two-lane highways) was stratified in order to obtain information on all existing combinations of possibly contributing causal elements. Subsequently, a screening of these variables was performed, using the Automatic Interaction Detection (AID), a multivariate analysis technique which indicates the way explanatory variables interact and the importance of individual variables in the explanation of variation. The results of AID analysis led to the formulation of the accident estimation models, using multiple regression techniques. It should be noted that the dependent variable was expressed in terms of number of accidents in a 2 mile roadway segment for a 4 year period, rather than in terms of accident rate. The authors' belief that the ultimate figure of merit is the number of accidents and that the use of rates can be misleading, is not further supported by an explicit argument.

As regards the total accident estimation model, since the stratification was dominated by ADT, four different relationships were developed, each corresponding to a different ADT range.

For ADT < 750, $y = 0.024(ADT)^{0.70}(PSR + 1)^{0.18} - 1$, $R^2 = 0.34$ (7)

For $750 \leq ADT < 1500$, $y = 2.54(PSR + 1)^{0.24} - 1$, $R^2 = 0.26$ (8)

For $1500 \leq ADT < 3500$, $y = 0.016(ADT)^{0.69}(PCL + 1)^{0.068}(OB20 + 1)^{0.29} - 1$, $R^2 = 0.32$ (9)

For $ADT \geq 3500$, $y = 0.12(ADT)^{0.46}(NC + 1)^{0.35}(OB20 + 1)^{0.21} - 1$, $R^2 = 0.49$ (10)

where: y = number of accidents in a 2 mile roadway segment for a 4 year period; PSR = percentage sight restriction; PCL = percentage of segment length curved; OB20 = percentage exposure length to objects within 20 foot; NC = number of curves.

The authors point out that, in order to evaluate correctly the variance explanation by these models (which may appear rather low, looking at the values of R^2), it is necessary to take into account that about 70% of the variance has already been explained by the ADT stratification. This consideration leads to the conclusion that the entire variance explanation by these models exceeds 82%.

A separate estimation model was calibrated for injury and fatal accidents; in this case, since the effect of ADT was found to be not so important as for total accidents, only one relationship was developed to model the accident experience:

$$y = 0.039(ADT)^{0.52}(PCL + 1)^{0.096}(OB10 + 1)^{0.069}(STIFF) - 1, \quad R^2 = 0.49 \qquad (11)$$

where: y = number of injury-fatality accidents in a 2 mile roadway segment for a 4 year period; OB10 = percentage exposure length to objects within 10 foot; STIFF = object stiffness (this variable assumes a value of 1.36 if unyielding objects exist within 14 foot of the edge of the pavement, and 1.17 otherwise), and the remaining variables have the previously defined meaning. It is worth noting that in this model the variable representing the restriction on passing sight distance (PSR) does not appear at all. Indeed, it was found that injury accident occurrence is more sensitive to horizontal alignment than the less severe accidents and that vertical alignment (an important component of the passing sight restriction) is less important in injury accidents.

The AID analysis also revealed that on high-ADT roadways with high exposure to roadside objects and lengthy curved segments, the pavement width had an important effect on injury accidents experience: in particular, it was found that for this category of highways the 20 foot wide and the 22 foot wide pavements had 1.5 times as many injury accidents as do 24 foot wide pavements. It may be further observed, comparing equation (11) with equations (9) and (10), that the number of injury accidents is more affected by closer objects than the number of total accidents.

Finally, a partial validation study of the models was performed. Due to time and fund constraints, only the low-ADT total accidents prediction models were tested ($ADT < 750$ and $750 \leq ADT < 1500$ ranges) based on segments not used in the model formulation and calibration.

The comparative analysis of actual versus predicted accident occurrence (conducted under the assumption that the number of accidents has a Poisson distribution) showed a generally good fit for most of the segments. The

modeling approach adopted in this study can be used for the preliminary evaluation of programs for the removal of roadside obstacles (it is worth noting that the roadside slope is not taken into account), or, more generally, for an overall evaluation of systemwide accident improvement potentials.

Moreover, the above mentioned comparison of actual versus modeled accident experience may turn out to be particularly meaningful, since it allows to identify the set of segments that are "outliers" in the sense that they have higher accident frequencies than "normally" expected. These locations are likely to be affected by some factors that are not adequately represented by the variables included in the models and/or by the structures of the models, and therefore may require specific and perhaps more detailed analyses. Particular consideration should, of course, be given also to the segments that behave in accordance to the model but have high accident rates (in an absolute sense).

A significant methodological contribution on the problem of cost-safety-effective roadside design is reported in Appendix H ("Research requirements for roadside considerations") of NCHRP report 197 (1978). The approach adopted in this research introduces the integration of roadside considerations into the overall cost-safety-effective design framework. addressed in NCHRP 3-25 project. The interest of such an approach is that the problem of roadside design is analyzed in a more general perspective aimed at the simultaneous consideration of all the roadway and roadside elements in the design process. However, even though this approach would be the most correct from a conceptual viewpoint, it is easily understood that

the actual implementation of a methodology for overall optimal design is a difficult task.

The general purpose of the research reported in Appendix H is to provide a methodology for establishing a relationship between roadside design characteristics and accident frequency and severity, in order to estimate future accident patterns under various design specifications. Given the difficulties that are encountered in trying to develop a model which relates directly the accident rates to the actually measurable roadside features (such as number and size of obstacles, embankment slopes, types of ditches, etc.), the use of "intermediate indicators" is suggested. These indicators, which can be obtained from the direct measures, should be of a "continuous" type (as opposed to the directly measurable features which are in general "discontinuous"), so as to make possible the formulation of a meaningful relationship between accident rates on roadway segments and the indicators themselves.

In a more formal way, instead of attempting to establish directly the following relationships:

$$\text{Accident Frequency} = f_1 \text{ (direct measures)} \tag{12}$$

$$\text{Accident Severity} = f_2 \text{ (direct measures)} \tag{13}$$

The suggested approach is to estimate first:

$$\text{Indicators} = f_3 \text{ (direct measures)} \tag{14}$$

and then obtain the relationships:

$$\text{Accident Frequency} = f_4 \text{ (indicators)} \tag{15}$$

$$\text{Accident Severity} = f_5 \text{ (indicators)} \tag{16}$$

The general procedure to be used in the cost-safety-effectiveness approach to roadside design is outlined as follows:

1. Direct measures are made on the existing roadside, or, in the case of totally new construction, with respect to the prospective roadside under minimum improvement.
2. Proposed improvements are defined, ranging from minimum improvements, such as guardrail protection, to complete hazard abatement.
3. The indicator values are computed for the original system and for each of the proposed improvement alternatives.
4. The expected accident patterns for each alternative are estimated, based on the indicators values previously determined and applying relationships of the type (15) and (16).
5. The original roadside configuration, as well as each of the proposed alternatives, are evaluated for each segment under consideration. The previously developed relationships are used to project accident frequencies and severities for each segment.
6. The results of step 5 and the improvement costs are integrated into the overall design procedure such that the overall cost and safety effectiveness for each segment can be estimated including roadside considerations. This is to be integrated into the overall optimization procedures to obtain the design specifications that yield the most cost-safety-effective design (explicit reference is made to the NCHRP 3-25 economic methodology).

The report further contains some guidelines for the actual implementation of the above general procedure. The first step is the selection of a set of highway segments for the collection of data on roadside and roadway characteristics. Each segment is to be subdivided into homogeneous segments according to curvature, slope, surrounding terrain characteristics, and

other design factors that might affect accident causation significantly. Segments may be broken out further by any significant changes in roadside characteristics. Each segment is to be further subdivided into 100 foot lengths called "increments", that are the units upon which a roadside data point (set of roadside measurements) should be obtained. More specifically, it is suggested that for each increment the following data elements be gathered: location information; curvature indicator; hazard identification code and hazard descriptor code (according to a two-level hazard classification scheme produced by Texas Transportation Institute); increment type (according to the following classification: (a) no roadside hazards within 50 foot; (b) point obstacles only; (c) continuous obstacles only; (d) slopes only; (e) slopes and point obstacles; (f) slopes and continuous obstacles); number of obstacles in increment; average distance of each obstacle classification from the traveled roadway surface; distance from the edge of the roadway to the hinge point of the slope; slope steepness of foreslope; width of sloping bank given by the preceding item; width of ditch bottom; backslope steepness; width of backslope before significant leveling; type of ditch (e.g. trapezoidal, rounded, etc.).

The measurements taken for each increment should then be combined to form an indicator for each segment, and this indicator is to be further combined with the common geometric data for the segment. The result is a data base where each point (set of geometric, roadside and accident information) corresponds to one segment. The next step is to develop a relationship between the geometric and roadside variables and accident frequencies and severities, using regression or other statistical analyses. It is recommended that each category of roadway facilities be handled separately.

In the data collection process, a trade-off between accuracy and sample size should be explicitly considered.

The report under consideration also includes a section devoted to the explicit formulation of the hazard indicators which are to be computed, for each homogeneous segment, combining the above mentioned variables. A different set of indicators is given, depending on the increment type as previously defined; for example, for the "Point obstacles only" type, three indicators are proposed: the average obstacle distance, the average obstacle density and the average obstacle severity.

A run-off-road accident analysis was conducted by the Minnesota Department of Transportation (1980) as a part of a more general study of accident occurrence on two-lane rural trunk highways. This analysis was based on data at statewide level ranging over the period 1977-1979. The variables considered were the following: shoulder surface type (grouped into three categories); shoulder width (categorized by one foot increments of width up to 10 feet plus one grouping for 10 through 12 foot widths); lane width (three categories); ADT (five categories). The accident data were classified according to three levels of severity (Fatal, Injury and Property Damage Only). The total data base consisted of 8,085 miles of highway, with 14,121 million vehicle-miles of travel. No correlation was found between accident rates and ADT, shoulder type and lane width. The only variable that turned out to affect significantly the run-off-road accident rates was the shoulder width; a least squares estimation of the corresponding relationships was performed for highways with 12 foot lanes and gravel shoulder, producing the following results:

$$A_{FR} = 0.011 - 0.0004\ S \tag{17}$$

$$A_{F+IR} = 0.25 - 0.012\ S \tag{18}$$

$$A_{TR} = 0.53 - 0.023\ S \tag{19}$$

where:

A_{FR} = run-off-road fatal accident rate per MVM;

A_{F+IR} = run-off-road fatal + injury + accident rate per MVM;

A_{TR} = run-off-road total accident rate (fatal + injury + PDO) per MVM;

S = shoulder width (in feet).

Based on these relationships, the cost of all run-off-road accidents on highways with various shoulder width was computed. The value corresponding to a shoulder width of 10 feet was compared with the run-off-road accident cost for highways with 10 foot shoulders, 30 foot clear zone and 6:1 inslope (as resulting from a specific study which will be discussed later). Assuming that the difference between the two cost values could be entirely attributed to the effect of the 30 foot clearance and of the flatter inslope, the savings in accident costs deriving from the implementation of the higher roadside design standards were calculated (again as a function of shoulder width). Based on the present worth of 20 years of savings in run-off-road accident costs at the maximum ADT permitted by the proposed (lower) reconditioning standards, it was determined that extensive expenditures to provide 6:1 inslopes and 30 foot clear zones were not justified.

As previously indicated, a more specific study was also performed by the Minnesota DOT (1980) in order to assess the effect of the roadside slope on accident rates for two-lane rural trunk highways. In particular, the objective of this study was to compare the safety performance of the 6:1 design policy versus that of the 4:1 design policy. The criterion adopted for the selection of the sample was to consider highway segments with 4:1

and 6:1 inslopes that had similar roadway geometrics and traffic volumes, in order to reduce as much as possible the influence of these variables on the number and severity of accidents. The use of this criterion yielded a sample consisting of 24 segments for each of the two roadside design policies. The accident analysis was again based on run-off-road accident records for the period January 1, 1977 - December 31, 1979. It is worth mentioning that in this study the proportion of unreported run-off-road accidents was estimated to be 30%; however, in the report it is pointed out that the impact of this factor on the conclusions of the analysis is likely to be of limited importance, since the missing accidents generally involve either property damage or minor injuries.

The data for the whole sample show that the ratio of total run-off-road accidents (all severity levels) on 4:1 mileage to total run-off-road accident on 6:1 mileage was found to be 2.8. The analogous ratio for fatal accidents only turned out to be 2.5, but the number of this type of accidents was very small and, therefore, of questionable reliability.

The proportion of fatal accidents was found to be 3.7% for the 6:1 segments and 3.4% for the 4:1 segments; the comparison of this result with the statewide breakdown for all types of accidents (0.7% fatal, 28.4% injury and 70.9% PDO) agrees with the findings of several other studies that rural run-off-road accidents are generally more severe than total accidents as a whole.

The data expressed in absolute values (number of accidents) were further converted to accident rates (accidents per million vehicle-miles); the rates for the 4:1 mileage were found to be significantly higher than those for the 6:1 mileage, for each of the three severity levels.

Based on these data, a cost-benefit analysis was carried out to determine whether the reduction in accident rates did offset the increased construction costs. It was assumed that the average accident rates obtained for the study segments were applicable to all two-lane rural highways. Other assumptions for the cost-benefit analysis were a service life of 20 years, a discount rate tied to the interest rate paid on long term U.S. Government bonds, and a traffic growth of 1% per year.

The computation of the difference in construction costs between 6:1 and 4:1 policies was performed under a "minimal" hypothesis, in the sense that only earthwork costs were considered (thus disregarding other costs, such as those deriving from increased amount of right of way necessary and from increased length of culverts). It is also emphasized that, in general, the increase in construction costs may vary considerably depending on the specific conditions of each project. The comparison of this "minimal" construction cost with the benefits accruing from accident rates reduction led to the conclusion that 6:1 inslopes were not economically justified on rural two-lane highways for projected ADT's less than 2000.

In the study conclusions it is further recommended that in a more detailed analysis benefits other than those deriving from accident reduction be taken into account when comparing different roadside slopes (for instance reduced maintenance costs connected with reduced erosion problems and reduced snow and ice control costs).

One of the most extensive research efforts on the problem of clear zones was carried out by the Midwest Research Institute (1982) and is documented in the NCHRP Report 24.7. The objectives of this study were to evaluate the safety effectiveness of clear zones of differing slopes and

widths, in terms of reduction of the number and severity of single-vehicle run-off-road accidents, and to outline a methodological framework for a cost-effective application of the clear zones in design practice. The highway types considered included two-lane highways, four-lane freeways and four-lane divided nonfreeways; specifically excluded were low-volume highways (ADT < 750) and highways with urban development.

The general approach adopted for the analysis of the safety effectiveness of clear zones was the comparison of the actual accident experience for existing highway segments constructed under different roadside design policies. The information source for the study consisted of three existing data bases from Illinois, Minnesota and Missouri, including segments of the three highway types previously mentioned; all of the study segments had 55 mph speed limits. Accident, geometric and traffic data for a total of 836 study segments were considered, with an overall exposure of over 41 billion vehicle-miles for 4,601 miles of roadway. The corresponding total accident experience was equal to 11,649 single-vehicle run-off-road accidents over an average study period of 4.4 years. The roadside design policies identified on the sample segments were grouped into three different categories, intended to represent the most typical roadside configurations actually implemented with respect to lateral embankment slope and presence of fixed objects outside of the shoulder.

The 6:1 Clear Zone roadside design policy was characterized by foreslopes of 6:1 or flatter within 30 foot of the traveled way. The actual average embankment foreslope for this policy was found to be 5.8:1 for two-lane highways, 6.9:1 for freeways and 5.7:1 for four-lane divided

nonfreeways. These segments were generally, but not completely, clear of roadside obstacles within the 30 foot clear zone.

The second roadside design policy, called 4:1 Clear Zone, had a prevailing foreslope of 4:1 or flatter within 30 feet of the traveled way (but often 3:1 or 2:1 slopes on fills higher than 10 to 15 feet were found), with an actual average embankment slope of 3.7:1 for two-lane highways, 4.3:1 for freeways and 4.2:1 for four-lane divided nonfreeways. Freeways constructed under this policy had generally a 30 feet roadside clearance, while on two-lane highways unprotected fixed objects within 30 foot were found to be present in a substantially higher number than under the 6:1 Clear Zone policy.

Finally, the Nonclear Zone roadside design policy was dominated by segments with 3:1 and 2:1 embankment slopes and little or no control of unprotected obstacles outside of the shoulder. This roadside configuration was found on two-lane highways and on four-lane divided nonfreeways, but not on freeways. The average embankment foreslope turned out to be 3.1:1 for two-lane highways and 3.5:1 for four-lane divided nonfreeways.

The analysis of accident occurrence for the sample segments, grouped according to the above defined categories, indicated the existence of a statistically significant relationship between single-vehicle run-off-road accident rate and roadside design policy for all highway types considered. This analysis was based on the comparison of the mean accident rates found for each highway type and roadside design policy, both for all severity levels and for fatal and injury accidents only. It should be noted that these mean accident rates were adjusted to take into account the effect of independent variables other than roadside features, that were considered to

affect significantly the accident experience. Specifically, the variables explicitly considered in the analysis were state, ADT, and shoulder width. The only highway type-roadside policy combination for which no experimental data were available was the Nonclear Zone policy on freeways, and an estimate of the corresponding accident rates was obtained applying the NCHRP 148 roadside hazard model.

The difference between the mean accident rates for a given pair of roadside design policies (and for a specified highway type) can be interpreted as a measure of the safety effectiveness deriving from the improvement of the roadside configuration for that type of highway. These accident rates differentials were found to be consistent with the hypothesis that the roadside safety performance improves when switching from a lower to a higher policy (for example, from 4:1 Clear Zone to 6:1 Clear Zone), both for total accident rates and for fatal plus injury accident rates. Moreover, as said before, these differences were found to be statistically significant. However, it is to be remembered that these indicators are average values and the corresponding "local" values are likely to vary from one location to another, given the stochastic nature of the accident occurrence.

Another interesting result of the analysis was that the accident severity distribution did not vary between roadside design policies. In particular, segments with improved roadside design did not show a distribution characterized by less severe accidents. Based on this result and on the previously discussed absolute decrease in accident rates, the authors concluded that roadside design improvements are equally effective in reducing fatal, injury and PDO accidents.

A further phase of the study was devoted to a modeling effort. An attempt was made to develop an explicit functional form which relates the single-vehicle run-off-road accident rate to ADT for each combination of highway type and roadside design policy.

A statistically significant linear relationship between accident rate and ADT for each of the three design policies was determined for two-lane highways, but not for freeways and four-lane divided nonfreeways. Since the slopes of the three linear functions calibrated for two-lane highways were not significantly different, a single common slope was adopted. Thus, the model is expressed by the following relationship:

$$AR = -0.041\ ADT + b_o \quad (20)$$

where: AR = single-vehicle run-off-road accident rate (accidents per million vehicle - miles); ADT = average daily traffic volume, 1,000 vpd; b_o = a constant that depends on the roadside design policy.

It is pointed out that this model is valid within the ADT range for which data were available on two-lane highways (750 to 5,000 vpd). A similar relationship was calibrated for fatal plus injury accident rate on two-lane highways, yielding a common slope of -0.026 accidents per million vehicle-miles per 1,000 vpd.

It is worth noting that in each of these models the accident rate decreases with increasing traffic volume. This result agrees with the findings of several other studies.

In order to provide some insight into the cost-effectiveness framework, four design examples were developed by the authors. A benefit-cost analysis based on the B/C ratio criterion was performed. The comparison of the present worth of accident cost savings and construction costs was based on a

temporal horizon of 20 years, assuming a discount rate of 4% per year. Since the differences between the roadside design policies in accident frequency (and therefore in the cost-benefit ratio) were found to increase with increasing ADT, the design examples also include the determination of the "breakeven" ADT value, i.e. the minimum traffic volume at which a roadside design improvement on an average highway segment would be cost-effective. Two different accident cost estimates were used in the computation of the "breakeven" ADT, namely the National Safety Council estimates and the National Highway Traffic Safety Administration estimates. For this reason, the results of this analysis are given in form of ADT ranges rather than in form of single ADT values.

The design examples show for freeways that the improvement from a Nonclear Zone to a 4:1 Clear Zone roadside design policy becomes cost-effective for an ADT between 3,820 and 5,410 vpd. Again for freeways, the use of the 6:1 Clear Zone policy is seen to be economically justified for an ADT range from 6,100 to 8,650 vpd. The breakeven ADT's for two-lane highways were found to be characterized by a greater indetermination, mainly due to the higher variability of the roadside configurations and of the costs of roadside improvements, compared to freeways. The results of the design examples for two-lane highways indicate that the shift from the Nonclear Zone design to the 4:1 Clear Zone policy could become cost-effective anywhere in a broad ADT range from 750 to 4,930 vpd. An improvement from the 4:1 Clear Zone to the 6:1 Clear Zone would be justified for an ADT of at least 1,560 to 2,450 vpd.

The authors point out that the results of these design examples should not be interpreted as representing generally applicable design policies. It

is emphasized that a great deal of flexibility is needed in order to select the most cost-effective roadside design for each segment of highway. In fact, the cost-effectiveness of roadside improvements can vary widely between highway segments based on accident rates, traffic volumes, construction costs and other factors. This implies that the use of single, fixed roadside standards should be replaced by a design process, based on cost-effectiveness considerations, which yields the roadside design most suited to each individual highway segment or to groups of highway segments that are similar in type, functional class and traffic volume.

It is also stressed that the safety measures of effectiveness developed in this study (reductions in mean accident rates) represent average values for the three states whose data were considered. The circumstance that substantial state-to-state variations in accident rates were found, even among these three states located in the same part of the country, indicates that highway agencies should adapt the results of this study to fit local conditions.

It is also suggested that locations with extremely high or extremely low roadside accident occurrence be identified, where possible, and that the measures of effectiveness for improving such locations be adjusted accordingly. More generally, the authors recommend that, even when--for legal and administrative reasons--highway agencies may desire to adopt a set of design standards (possibly different for highways of different functional class and traffic volumes), sufficient flexibility be retained in design policies so as to allow modified designs for locations with extremely high or extremely low values of construction cost and/or safety effectiveness.

NCHRP Report 247 further includes a set of appendices. Appendix A is devoted to a review of literature dealing with roadside safety and of past and current trends in roadside design practice. Appendix B describes the project data base (identification of study segments, collection and processing of data on roadside design, roadway geometrics, and accident experience). Appendix C contains the description of a field survey that was conducted on a randomly selected sample of highway segments in order to integrate the existing data base. Appendix D documents the statistical analysis performed on accident data to estimate the differences in accident occurrence between roadside design policies. Appendix E includes a comparison between the accident rates found in the project data base and those estimated using the NCHRP Report 148 roadside hazard model and an evaluation, via the same model, of the run-off-road accident rates for several roadside configurations that were not found in the set of segments considered. Finally, Appendix F presents the previously mentioned four design examples that were developed in order to illustrate the cost-effectiveness approach which is proposed for the analysis of roadside design improvements.

4. Conclusions and Needs for Future Research

Based on the preceding literature review, it is possible to highlight the most significant findings of the studies examined and to indicate some of the major issues that should be addressed in future research on the problem of roadside design.

These findings and needs for future research can be summarized in the following points:

1. The conclusions reached by the various research efforts are not unanimous; in fact, some studies indicate the existence of a

statistically significant relationship between accident occurrence and roadside design, while others do not. With respect to this crucial issue, there is a need to investigate to what extent the results of the various analyses may be affected by elements which are not intrinsic in the phenomenon under consideration (such as, for example the particular statistical technique used).

2. The single-vehicle run-off-road accident rate is consistently shown to be a decreasing function of traffic volume. A possible explanation of this pattern is that generally high-volume roadways have better geometric characteristics and lower operating speed, so that the probability of run-off-road accidents, as expressed by the ratio (number of accidents)/(level of exposure) is lower on this type of highways.

3. The roadway variable which appears to be the most important in terms of causation of run-off-road accidents is the horizontal alignment of the highway. Further research is needed to assess the quantitative impact of this variable on accident rates in comparison with that of roadside design.

4. Most of the studies examined tend to express the roadside configuration mainly in terms of presence of fixed objects (or, equivalently, width of the obstacle-free area), while less emphasis is placed on the variable "embankment slope". This may be possibly considered one of the reasons for the fact that some studies did not find a significant relationship between roadside design and accident experience.

5. A comprehensive approach to the roadside safety problem would require the consideration of variables other than roadside and roadway characteristics and traffic volumes; in particular the role of driver and vehicle characteristics, as well as that of some environmental conditions (such as weather, darkness, etc.) should be explicitly taken into account. This seems to be one of the major gaps in the current approaches to the roadside safety problem.

6. Another issue not addressed in the current research is the evaluation of the need for accuracy in the estimation and modeling of accident occurrence relative to the accuracy achievable in the successive phases of the cost-effectiveness analysis. It is evident that the great indetermination faced when trying to attribute values to variables such as the monetary cost of accidents, may make unnecessary a high level of accuracy in the estimation of other variables. Useful indications about the magnitude of the errors that may derive from the different variables involved in the analysis, could be obtained by performing some sort of sensitivity analysis.

7. Further research is needed on the roadside encroachment phenomenon, in order to provide a suitable basis for the development of simulation models. The goal of an effort in this area should be to update and integrate the results of the work done by Hutchinson and Kennedy, which represents the only empirical study now available on this subject. In particular, a key issue to be addressed is that of finding the most appropriate measure of the

level of exposure to run-off-road accidents. The exposure measure currently used is the amount of vehicle-miles of travel on a given segment, but evidently a more meaningful indicator would be the frequency of roadside encroachment. An extensive data collection effort could provide the basis for developing some relationship between encroachment rates and more easily measurable variables, such as geometric characteristics of the roadway and traffic conditions.

8. The current literature indicates that a major problem in roadside accidents estimation is the fact that single-vehicle run-off-road accidents are heavily underreported. Specific research is needed to obtain some estimate of the error incurred when using only reported accidents data, in order to develop corrective coefficients to be applied to the data sets usually available.

9. An important issue to be considered in future studies is the extent to which the roadside design affects the drivers' perception of safety. This interdependence between roadside configuration and drivers' behavior is very likely to have some impact on the actual run-off-road accident rates. The question of what is the importance of this effect relative to the other accident-causative factors should be addressed within a micro-modeling framework.

10. Some research effort could be devoted to the analysis of long-run time series of run-off-road accidents in order to identify the possible existence of trends that could be related to long-term variations in some key variables such as drivers' behavior, vehicle characteristics, etc.

11. Specific consideration should be given to the existence of secondary benefits and costs (other than accident reduction benefits and construction costs) deriving from improvements of roadside design policies.

12. Given the broad variability of accident rates, traffic volumes and construction costs that may exist among different highway locations, the cost-effectiveness procedure should retain the maximum possible degree of flexibility. This would imply that the cost-effectiveness evaluation be carried out on a project-by-project basis; however, since highway agencies are usually confronted with the need of indicating a set of design standards of general applicability, a trade-off between total flexibility and total rigidity will result in practice.

13. Finally, the most important area for future research is certainly that of the overall optimal design. That is, the problem of roadside safety should be addressed within a more general analysis framework, where not only roadside design features, but also roadway geometrics are considered as decision variables. This is the only approach which insures that the solution yielded by the cost-effectiveness analysis is indeed a "global optimum", and that the maximum return is obtained from the funds available for improvements.

References

American Association of State Highway Officials (1967) Highway design and operational practices related to highway safety, Washington, D.C.

American Association of State Highway and Transportation Officials (1977) Guide for selecting, locating, and designing traffic barriers, Washington, D.C.

Cerrelli, E. C. (1984) "Preliminary report, 1984 traffic fatalities," NHTSA.

Cleveland, D. E. and R. Kitamura (1978) "Macroscopic modeling of two-lane rural roadside accidents", Transportation Research Record 681.

Dotson, V. E. (1974) An evaluation of the thirty foot clear zone, M.S. thesis, University of Illinois, Urbana.

Foody, T. J. and M. D. Long (1974) The identification of relationships between safety and roadway obstructions, Ohio Department of Transportation, Columbus.

Glennon, J. C. (1974) "Roadside safety improvement programs on freeways: a cost-effectiveness priority approach", National Cooperative Highway Research Program Report 148.

Graham, J. L. and D. W. Harwood (1982) "Effectiveness of clear recovery zones", National Cooperative Highway Research Program Report 247.

Hall, J. W. and T. E. Mulinazzi (1978) "Roadside hazard model", Transportation Research Record 681.

Hutchinson, J. W. and T. W. Kennedy (1965) Medians of divided highways--frequency and nature of vehicle encroachment, Project IHR-59, University of Illinois, Urbana.

Illinois Department of Transportation (1983) Policies for the rehabilitation of highways and bridges on marked routes of the state highway system in Illinois, Springfield.

Minnesota Department of Transportation (1980) Evaluation of accidents on 2-lane, rural trunk highways.

Minnesota Department of Transportation (1980) Comparison of accident rates related to 4:1 and 6:1 inslopes on 2-lane rural trunk highways.

Missouri State Highway Commission, "Summary of accident experience on sections of road constructed with 20 foot 'Safety zones'", unpublished memorandum, cited in Graham and Harwood (1982).

National Safety Council (1984) Accident Facts, 1984 Edition, Chicago.

Roy Jorgensen Associates (1978) "Research requirements for roadside considerations", Appendix H, in "Cost and safety effectiveness of highway design elements", National Cooperative Highway Research Program Report 197.

Stonex, K. A. (1960) "Roadside design for safety", Highway Research Board, Proceedings, Volume 39.

Texas Transportation Institute (1980) A supplement to a guide for selecting, designing and locating traffic barriers (updated 1981).

Wright, P. H. and K. K. Mak (1976) "Single vehicle accident relationships", Traffic Engineering.

APPENDIX 2

Roadside Improvement Cost Estimates

(A) Unit Prices

Tree Removal	$150 ($11/inch of diameter)
Culvert Headwall Removal	$550/end ($375/cubic yard)
Entrance Culvert Removal	$600
Culvert End Section and Grate Installation	$2,000/end
Culvert Headwall Removal and Replacement	$2,500/end
Guardrail (Including End Sections)	$1,900 + $12/linear foot

(B) Roadside Project Costs: FAP Projects

	Project			
Improvement type	FAP 71	FAP 717	FAP 749	FAP 554
Entrance Culvert Removal			X	
Culvert Headwall Removal		X		
Culvert End Section and Grate	X	X	X	X
Tree Removal				X
Guardrail	X	X	X	X
Fence Relocation				X
Other	X	X		X
Cost/Mile ($)	17,000	33,000	40,000	25,000
Length (miles)	5.5	8.4	9.1	10.0

Roadside Project Costs: FAS Projects

Improvement type	FAS 642	FAS 151	FAS 526	FAS 516
	Project			
Entrance Culvert Removal	X	X	X	
Culvert Headwall Removal	X	X	X	X
Culvert End Section and Grate		X	X	X
Tree Removal		X		
Guardrail	X	X		X
Fence Relocation				
Other	X	X		
Cost/Mile ($)	10,000	10,000	14,000	13,000
Length (miles)	2.2	4.0	5.0	6.0